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THE METHOD OF UNDERGROUND MINING OF IRON ORE IN THE DISTRICT OF KRIVOY ROG

BY

W. AYVAZOGLOU

(TRANSLATED FROM THE ORIGINAL RUSSIAN)
OF
A. K. BOULDOVSKY

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METHODS OF UNDERGROUND MINING OF IRON ORE IN THE DISTRICT OF KRIVOY ROG[1,2]

Translated by W. Ayvazoglou[3] from the original Russian of A. K. Bouldovsky

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1 From the Mining Journal, Moscow, 1922.

2 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote of acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6254."

3 Translator, U. S. Bureau of Mines.

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INTRODUCTION

This paper has been translated from the Russian by the United States Bureau of Mines and is issued as one of a series of circulars dealing with mining methods and costs in connection with a general study of this subject sponsored by the bureau.

The paper presents some interesting features in connection with the methods employed in Russia and describes certain variations in standard methods which might conceivably be applied to a limited extent in this country.

The system employed by the author, wherein the efficiency of each mining method and variation thereof is measured by the volume of ore mined per linear unit of development, is interesting. While such a measure can not be considered a true indication of the efficiency of an operation as a whole, it constitutes a valuable guide in the selection of a mining method.

Some freedom has been employed in the translation, but literal translation has necessarily been used to a considerable extent also. The translation follows.

PREFACE

The yearly output of iron ore in the district of Krivoy Rog is about 70 per cent of the whole output in Russia (in 1913 about 6,500,000 tons). The ore of this region, forming a bed about 4½ miles long and approximately 350 feet thick at a shallow depth, has attracted the attention of industrial circles even outside of Russia.

The scientific-technical literature of the region of Krivoy Rog deals almost exclusively with the geological structure and genesis of the deposits. Very little information on the methods of mining used has appeared in the technical press.

Because of the small depth of the overburden, the mining up to the present has been accomplished mostly by open-pit methods. Underground mining increased gradually from the early years of the twentieth century, and by 1918 underground methods were used in most of the mines.

Peculiar conditions of the ore beds and great variations in the chemical composition and physical properties of the deposits brought about the development of new mining systems, successfully adjusted only after many careful trials, as well as the adaptation of systems already known. New methods are still being tried, and the adoption of final methods to conform to the conditions is still in the future.

One of the main difficulties in the way of improvement is the lack of sufficient knowledge of the methods and systems used abroad, as well as in our home country, as the descriptions and handbooks concerning the mining of iron-ore deposits are not satisfactory.

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My task is to describe the system of underground mining in the region of Krivoy Rog, and I hope that similiar attempts will be made by others also.

I. CHARACTERISTICS OF THE DEPOSITS AND PHYSICAL PROPERTIES OF THE IRON ORES OF THE REGION

a. Forms of Deposits. - The deposit forms are various but are mainly stratified. The stratified character of some of the deposits is so clearly expressed that they may be definitely classed among the stratified ore deposits. This can be said especially of deposits from 20 to 35 feet thick.

Deposits of greater thickness often differ from the stratified forms; they sometimes have pronounced local increases of thickness and swells, or, on the other hand, the thickness decreases so that the iron ore pinches out entirely or is replaced by other rocks.

The deposits of the region may be divided into three groups: (1) Stratified ore bodies; (2) those of stratified form with varied thickness and length along the strike and on the dip, and (3) ore bodies of the nest form. The first two groups consist of layers with a more or less well-defined footwall. The ore bodies of the last group mostly have forms trending in the direction of the main deposit and, being surrounded by barren rocks, their complete working-out is in most cases very easy.

b. The Elements of the Ore Deposits. - Almost all the ore deposits of the region have a trend close to that of the mean direction of the main ore body, about 15° NW. The length of single beds varies from about 150 to 700 feet.

The angle of dip of the beds is different in different parts of the region, but their main direction is to the West. The thickness, angle of dip, and the physical properties of the ore beds differ greatly, even for the same beds.

The angle of dip varies from a very small angle to 90°; if the beds are of stratified character the degree of the dip is sometimes uniform over a great distance. Thus the angle of dip of one of the best known and most profitable deposits, the Saksagansk second vein, is from 52 to 56° for a distance of about 25 kilometers. The following deposits have a dip of about 20°: One part of the Likhmanovsky vein, Dobrovolsky's, Polevoy's, Kolomoytsev's, and Rakhmanov's ore deposits, one part of the Inguletsk vein, and in the Inguletsk mine. The mean angle of dip for the whole region is about 60°.

The thickness of the deposits varies greatly. Often over a length of from 1,400 to 1,500 feet the thickness changes from 0 to 350 feet (in the Karnavatsk mine, for example). The mean value of the real thickness of the ore deposits of the whole region may be considered to be 70 feet. The extent along the dip is not constant either, but here the changes are not very sharp nor frequent.

The variation of the ore in thickness at depth has not been investigated sufficiently, owing to the lack of deep borings in this region; thus the total reserves of the deposits can not be estimated at present with any degree of accuracy.

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c. Physical Properties of the Ore. - The physical properties of the ore are closely allied with its chemical composition.

The ore of the region can be divided sharply into two classes: phosphorous iron ore with a high content of phosphorus and comparatively low content of iron, and nonphosphorous ore with a small content of phosphorus and rich in iron.

Phosphorous ore consists of a mixture of argillaceous slate and quartzite slate saturated with oxide of iron; the ore is of red-brown color; it has an easily divisible laminated structure; its hardness and tenacity are less than those of the nonphosphorous ore; sometimes the ore is even soft or loamy and, if mixed with water, is paste-like. It is characterized by the following chemical composition:

Fe---about 55 to 60 per cent.
P---about 0.05 to 0.3 per cent.
SiO_2---about 6 to 7 per cent.

The nonphosphorous ore consists of quartzite slates saturated with oxide of iron. Its structure and external appearance depend on the relative amounts of silica and iron. The structure of the ore is either compact or laminated. A high percentage of silica makes the ore very hard; sometimes it causes a powdery structure.

The nonphosphorous ore has the following chemical composition:

Fe---about 60 to 67 per cent.
P---about 0.05 per cent.
SiO_2---about 9 per cent (4 - 12%).

The iron ore of this region is mostly red hematite; very seldom, at the outcrops, brown hematite occurs. Sometimes local accumulations of specularite (Fe_2O_3) and micaceous iron ore are found. Granulated ore and small accumulations of magnetite are found only occasionally.

The mining of the ore deposits often becomes difficult because of their varying chemical composition and structure (as well as high specific gravity of about 5.0), as these properties change sometimes within a few tens of feet. Thus in some deposits the presence of layers of soft rocks, such as mixtures of ores with talc, chlorite, and clay, causes an easy separation at the surfaces of contact and often makes the deposits tend to slide. Layers of quartzite grains and poor quartzite ores often increase the possibility of sudden falls of earth.

Only a few deposits have a uniform ore structure. The structure of most of them is irregular, and the mining is done in ores ranging from powdery to very hard forms. The variations in stability of the ores during mining depend on their different structures.

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The great specific gravity of the iron ore (the weight of 1 cubic sagene, equivalent to 343 cubic feet, taken from the massive ore body is from 30 to 40 tons) requires the avoidance of large roof spans. The smallest spans of the roof must be used with nonphosphorous, powdery iron ore (called here "blue ore"); the width should not be over 10.5 feet and the length not over 42 to 56 feet; greater length requires additional support. The ore of medium quality, tenacity, and hardness allows increasing the width up to 28 or 35 feet and the length up to 70 to 84 feet; in case of smaller widths, of about 14 feet, the length may be increased up to 140 or 150 feet.

To increase the stability of the ore during working, the roof may be arched. At present this method is used as much as possible. The necessity of additional support is considerably lessened, and thus the work may be accomplished more economically.

The dehydration of the ore may improve its stability to a great extent. Layers of porous or weakly cemented low-grade ores, as well as some kinds of porous phosphorous and powdered ores, absorb water easily, becoming swollen and sometimes even deliquescent. The powdered ore in particular sometimes absorbs so much water that it is difficult to mine even in small stopes.

One of the problems of mining, therefore, is that of dewatering the ores. For this purpose main development openings (main drives at lower levels) or general development work (work affecting large areas and different levels of the ore deposits) are sometimes necessary. After being drained the ore becomes more stable, thus making mining possible.

d. Wall Rocks. - Wall rocks greatly affect mining. In this region these rocks consist mostly of iron-quartzite slates of varying hardness, but sometimes clay slates are encountered.

Where clay slates having a high content of chlorite or talc form the wall rock its stability, which in general is good in the region, is decreased to such an extent that special attention must be paid to this factor in selecting the system of mining.

II. PREPARATION OF DEPOSITS FOR UNDERGROUND MINING OF THE ORE

Since in most mines the underground mining was preceded by open works (quarries), the underground working began with inclined shafts deepened below the bottom of the previous open pits. At mines first worked by underground methods, however, development by means of vertical shafts is preferred because of the convenience of exploitation and saving in barrier pillars.

The leaving of pillars in shafts during mining is especially important, owing to the aforementioned properties of the ore body. If the pillars are left at wrong places, the collapse of the ore mass menaces the safety of the shafts and the buildings above them.

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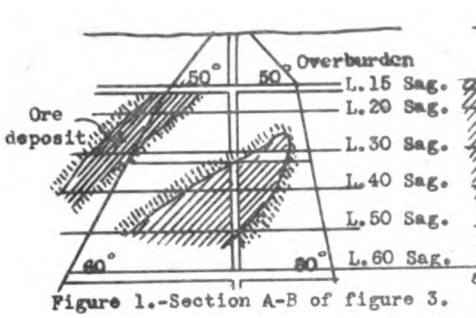

Figure 1.-Section A-B of figure 3.

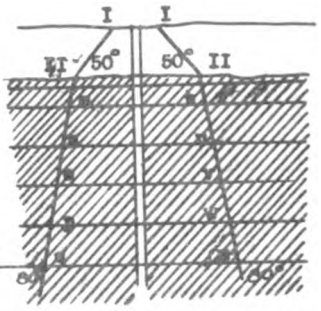

Figure 2.- Section C-D of figure 3.

LEGEND

The following symbols apply to all illustrations for this paper.

- Solid ore.
- Broken ore.
- Filling.
- Filling from neighboring places.
- Quartzite.
- Clay slates.
- Raise.
- Winze.
- Raise and Winze.

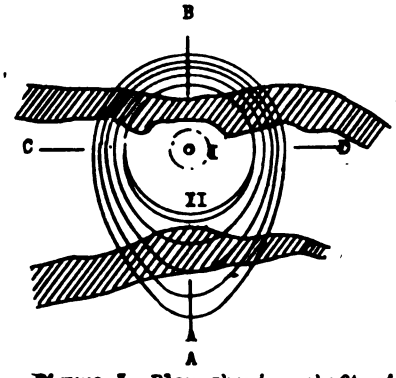

Figure 3.-Plan showing shaft pillar.

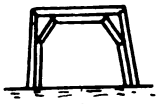

Figure 4.-

Figure 5.-

Method of timbering through wet ground

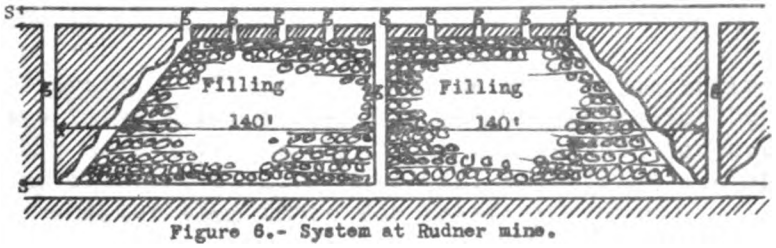

Figure 6.- System at Rudner mine.

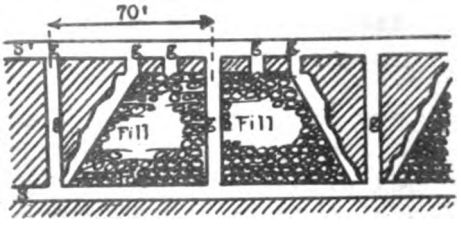

Figure 7.- System at Rakhmanov mine.

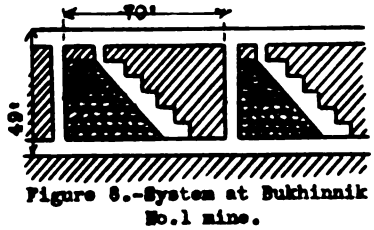

Figure 8.-System at Bukhinnik No.1 mine.

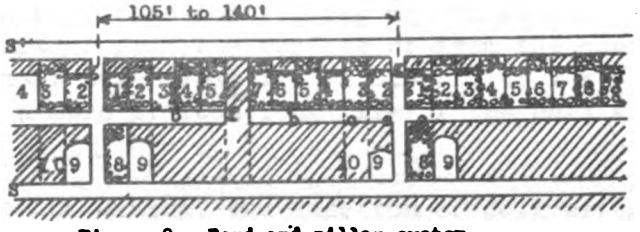

Figure 9.- Bord and pillar system.

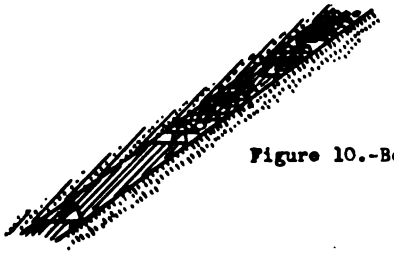

Figure 10.-Bord and pillar system.

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By leaving the pillars and fixing the limits of the sphere of action of the pillars, the tendency of the ore masses is to slide along the plane of the footwall; therefore the extent of the sphere of action of the pillars to the hanging-wall side of the ore deposit must be greater than to the other sides.

As an example of the determination of the line limiting the sphere of the pillars is mentioned the method of leaving the pillars which is used in one of the vertical shafts of Karnavat's mine (figs. 1, 2, and 3). Here the thickness of the overburden is about 100 feet.

On the surface near the shaft a barrier pillar, I, is left which has a radius of 35 feet from the center of the shaft (figs. 2 and 3); below in the overburden the area by which the sphere of the pillars is limited is formed at an angle of 50° (about the angle of repose) to the line connecting the circle on the surface of the ground; thus we have the circle, II, on the surface of the outcrop of the ore itself. The outlines of the sphere of the pillars in the ore body itself are established by the surfaces formed with the circle, II, - along the three axes, in the direction of the strike of the body and the direction of the footwall; an angle of 80°; and along the fourth axis, to the side of the hanging wall, an angle of 60°.

In the horizontal section the lines of intersection of the surface formed by the borders of the pillars at the surfaces of the levels are represented by oval contours; on the projection of the bed on the vertical plane (fig. 2) the borders for the levels are marked m-t, n-u, o-v, p-w, q-x. The ore of the pillars left near the shafts is thus lost, as they can be taken away only after the mine is closed entirely.

Shafts. - The shafts may be divided according to their purpose into two groups - those for hoisting the ore and those for bringing down the filling material; sometimes one shaft may be designed for both purposes. The shafts for bringing down the filling material, as well as the pillars left around them, are usually smaller than those for hoisting.

Up to this time building stones and filling materials have been thrown down through special holes, either from the surface or from the quarry bottom; these holes are usually of small size (from 7.62 x 2.8 ft. to 7 x 7 ft.); the barrier pillars required for a more or less long life of the hole are comparatively small.

With increase in depth of mining, the question of delivering the filling material from the surface to the stopes becomes more and more important. (The levels of almost all the mines are marked with regard to the level of the Azov Sea. The surface of the central part of the region is about 240 feet above the level of the Azov Sea. The greatest depth is reached by the workings in the Dubovaya Balka mine. It is about 980 feet below the surface of the earth or 910 feet below the level of the Azov Sea. The mean depth of most mines is from about 420 to 490 feet below the surface.)

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Another kind of pillar must also be mentioned - that used beneath the bottom of a quarry in order to protect the underground workings from any falls which may occur in the quarry, in the hanging wall, or from the penetration of water from the bottom of the quarry. In almost all mines in which open-pit mining has been followed by underground work, a protective pillar from 10.5 to 21 feet thick is left.

Time has shown that this pillar does not protect against the pressure of the hanging wall; after a certain time the pillar is crushed; also it does not protect against water which penetrates through cracks. There is a tendency, therefore, to replace these barriers by a clay cushion or to fill up the bottom of the quarry with waste from the neighboring pits. This method has been used by the Dubovaya Balka and Krasnokutsk mines with fairly good results.

III. SUPPORT AND FILLING OF UNDERGROUND WORKINGS

Drifts of comparatively small cross section usually do not need special support if their roofs can be arched. The shafts are generally timbered with 2 to 3 inch pine or sometimes oak; the sides and the roof of fractured deposits are supported by poles 1 to 2 inches thick, 2 to 6 sets of which are placed at 7-foot intervals. Sometimes it is not necessary to support these drifts and shafts at all, but in this case periodic examination of the walls and the roof must be made.

Shafts sunk through friable deposits must be lined thoroughly; 12 sets should be used every 7 feet; where there is water or the deposit is deliquescent additional sets must sometimes be used (figs. 4 and 5).

The winzes are usually only lightly timbered unless they are to be used as ore passes and are in the filling, in which case they must be reenforced by small posts or even by walling. The lining and the arrangement of the chute mouths of winzes used for ore passes require special attention. Due to the high specific gravity of the ore and the percentage of 2 to 2½ inch lumps (the percentage of the lump ore is usually about 20 per cent but sometimes reaches 60 per cent), lining with 1½-inch boards is necessary; posts and even old rails must be used for the reenforcement of chute mouths.

If mining is done under the filling from above downward, it is necessary to line the walls and support the filling with logs. Other systems do not require such strong reenforcing and use stulls set on sill pieces in working from the filling upward. (Fig. 31.)

Owing to the high specific gravity of the ore, a large mass may break away if the span is too long. Experience has shown that the pressure is so great that any support, even a pile of rock, can be crushed if measures of precaution are not taken; therefore, the rules concerning the length of span, careful filling, and wedging of the timber must be strictly observed.

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Careful filling is very important for safety in mining iron ore. As a rule, any empty space must be filled immediately, as the mining of the iron becomes impossible where spaces are left empty. The filling operation is very expensive; so that a careful organization of this work is important. The best filling material is a mixture of clay and small pieces of quartzite or limestone (Kolomoytzer's mine).

In dry filling, the material is compressed either by the weight of the upper part of the filling or by the pressure of the work performed over it; in some systems the filling depends upon its own weight for compression; as a rule, however, a sufficient density can not be obtained in this way, and the dry filling must be replaced by semiwet or wet filling.

Semiwet filling consists of layers about 15 inches thick. Each layer is watered and allowed to settle before another is placed and watered; the work is continued in this way almost up to the roof of the stope. Special long-handled shovels are used in filling empty places.

Wet filling is carefully ground and mixed with water on the surface and then brought down into the stopes under pressure through large pipes. This method is not used in Russia at present. Such "liquid" filling was formerly used in one of the mines, but the mixture was brought to the stopes in vessels.

Good results were sometimes obtained by using dry filling when the work above the filled space was continued. The monolithic condition of the filling permitted mining of the barrier pillars between the sections.

Dry filling shrinks to a certain degree: pure clay, 30 per cent, clay with quartzite, 15 per cent. The latter mixture was generally used. Experiments have shown that the best ratio is obtained with 25 per cent quartzite; if more than 30 per cent of quartzite was used, the whole mass easily separated into flakes.

Semiwet filling is most satisfactory when composed of clay or a mixture of clay and 25 per cent of granulated quartzite. The shrinkage in this case was as much as 50 per cent of the original volume. Test fillings of granulated quartzite unmixed with clay have given negative results. Thus it was established that the only satisfactory filling for the worked out spaces is clay and clay mixed with not over 30 per cent of granulated quartzite.

The material for filling is obtained either on the surface from old quarries or from special quarries, or underground from old workings or from the overburden.

The use of old fillings is becoming more and more common. As in this method the composition of the material is not very important, the advantage of this system is evident.

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IV. SYSTEMS OF MINING IRON ORE IN THE REGION OF KRIVOY ROG

Before starting a description and discussion of the systems of mining iron ore in the region, it is necessary to mention that no matter what system is used, the pillar lines on the different levels must always be matched in a vertical line. Because of frequent change in direction and dip of the ore bodies, the lines can not be matched without surveying the mines; thus the organization of surveying parties is absolutely necessary. Without these surveys the exact matching of the work on different levels is impossible and falls of large masses are probable.

Two general systems are used, depending upon the thickness of the deposits: Systems of mining deposits of small thickness (from 14 to 21 feet), and systems of mining deposits of great thickness.

As we will see later, all the systems in the second group require the driving of main drifts through the wall rocks, usually in the footwall. Only in exceptional cases, where the surrounding rocks are very hard or some other adverse conditions exist, do the drifts pass through the ore body itself; then the barrier pillars left to support the drifts must be considered lost.

The following order is used in the descriptions below:

First a system is described which may best be adapted to an average case. Such a system, however, owing to the wide variations in the bedding and in the properties of the ore itself, may be used in only a few mines. All the variations applied to the different conditions are mentioned, and after the principal characteristics of the system and its economy are described, its important advantages and disadvantages are given.

The degree of economy of each system is determined by a special method, as follows: The greatest expense in mining the ore is that of the preparatory work - construction of drifts, winzes, crosscuts, etc. The expenses in different sections of the Karnavatsk mine per 40 pounds of ore, according to the figures of 1915, were as follows: Cutting, including the preparatory work - 1.368 copecks;[4] shovelling, including that in the drifts - 1.578 copecks; filling - 0.640 copecks.

Therefore, in addition to the character of the mining work and its productiveness and economy, it is important to know the relation between the amount of ore produced and the necessary development work. For this reason the author, besides citing the advantages and disadvantages of mining by a certain method, has figured the coefficient of economy (the relation of the volume of the developed ore to the amount of development work) for each method. To make this computation the volume of the ore to be taken and the length of necessary preparatory and cutting-out work must be established. Their ratio - that is, the volume of the ore per unit of length of preparatory work - serves as the expression of the economy. This method is not very correct, of course, but it gives a fairly good estimate.

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4 One copeck is worth about half a cent.

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The actual mining of the ore by means of almost all known methods can be divided into two periods: First, the period of mining and filling of certain stopes along the strike, divided one from another by ore left in temporary barrier pillars; second, the period of mining the temporary barrier pillars. A certain length of time, depending on the nature of the system used, elapses between these two periods.

A. Systems of Mining Ore Deposits of Small Thickness

For the mining of ore deposits of small thickness, systems very different from those for mining ore deposits of large thickness are employed. The following systems are used in ore deposits of small thickness: (1) Continuous system along the strike of the ore--overhand stoping; (2) the bord-and-pillar system along the strike of the ore; and (3) the crosscut system - mining the ore by slices perpendicular to the strike of the ore deposit.

The first two methods are used exclusively for mining ore deposits of small thickness having an angle of dip greater than 40° and ordinarily not less than 60°. The third system is also used for ore deposits over 15 feet thick, but in mining thin ore deposits it is used mostly if the dip of the ore deposit is slight, not over 40°; as there are no particular differences in the use of this method for different degrees of thickness of the ore, the description of this system is given in the chapter dealing with the mining of thick ore bodies.

1. Continuous System Along the Strike of the Ore (Overhand Stoping). - This system is used in the following mines: Rakhmanov, Bukhinnik, Kolomoytsev, Rudner, Chervonny, Tarapakovsky, and Nadejda.

Where the deposits become very thick, however, these mines use other systems. This system is also used in other mines at places where the condition of the deposits is favorable for it.

The overhand stoping system is especially used in the Rudner and Rakhmanov mines. In the Rudner mine, in which the average thickness of the ore deposit is 7 feet and the angle of dip is from 60 to 70°, the footwall consists of quartzites and the hanging wall of clay slate; the height of the levels along the slope is 70 feet.

At every 140 feet along the strike of the ore body, main winzes (g, fig. 6) are driven, from every other one of which a pair of stopes is opened. In advancing the stopes, safety pillars measuring 7 feet along the dip are left under the drift on both sides of the main winze; in this pillar winzes are driven every 17 feet for communication and for the delivery of filling material.

The stopes are strengthened every 5 feet by props placed normal to the plane of the dip. The roof and the floor are covered with boards. The filling material is put below on the stulls of the lower drift and follows carefully along the line of the advancing stope. The floor is covered with 2-inch boards placed parallel to the line of the stope and remaining behind it not farther than 14 to 17.5 feet.

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The floor boards are not much used at present because by employing clay filling it is possible to use the surface of the fill as the bottom of the stope on which the workers stand and on which the ore is thrown; the filling is tamped lightly during the work so that it can also serve as a bed from which to shovel the ore.

The Rakhmanov mine uses a level interval of 56 feet and a distance between the main winzes of 70 feet in places where the thickness of the ore is not over 14 feet. The angle of dip is from 45 to 80°; the footwall consists of quartzites and the hanging wall of clay slates. The scheme of work is shown in Figure 7.

The other mines usually employ a level interval of 42 to 56 feet and a distance between the main winzes of 70 feet.

The scheme of the work in the Bukhinnik No. 1 mine is shown in Figure 8.

2. Bord-and-pillar System With the Pillars Along the Strike of the Deposit and Mining by Rise Workings. - This system is used in the Inguletsk mine, where the average angle of dip is from 35 to 60° and the average thickness is 10.5 feet. The footwall consists of quartzites and the hanging wall of clay-talc-chlorite slates of medium stability. The distance between the drifts is from 105 to 119 feet; the level interval is 63 feet. The winzes, g, are installed along the strike of the deposit at intervals of 100 to 135 feet (figs. 9 and 10).

At half the distance (49-56-63 ft.), stopes about 10.5 feet wide are opened from the winzes upward through the whole thickness of the ore; when the bottom of the upper drift is reached, the stopes are filled, leaving below at the wall of the sublevel a space of about 5.6 feet supported by a drift stull.

Mining is continued, according to the numbering given in the figure, to the middle sublevel drift (c, c, fig. 9). In the lower sublevel the rise working is accomplished in the same order as in the upper one; work must not be done in both sublevels at the same time; it is absolutely necessary that the stope of the lower sublevel be behind the upper stope at least 70 feet.

In order to support the upper drift, barrier pillars 10 feet thick are left beneath it at 10-foot intervals. If the hanging wall contains talc slate it is sometimes impossible to take out the ore along the whole section, so that the section must be divided into two parts and a barrier pillar, f, 7 to 10.5 feet thick must be left (fig. 9). This barrier pillar usually can not be recovered when the level is abandoned.

The order of taking out the pillars is shown in Figure 9. Only after taking out pillar 1 and completing the filling, can the simultaneous taking out of pillars 2, 3, etc., be accomplished.

Coefficients of economy obtainable by using the overhand stoping system and the pillar system along the strike of the ore body are estimated as follows:

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Thickness, 2 sagenes; (one sag. is equal to 7 feet); angle of dip, 50°.

Comparison of cost of overhand stoping system and pillar system

Overhand Stoping System		Pillar System	
Volume of the Ore in the Section Mined			
	Sagenes		Sagenes
Thickness	2.00	.....	2.00
Vertical height of the level ..	8.00	.....	9.00
Along the strike	10.00	.....	15.00
2.00 x 8.00 x 10.00 = 160 cu. sag.		2.00 x 9.00 x 15.00 = 270 cu. sag.	
Amount of Preparatory Development Necessary			
	Sagenes		Sagenes
Drift	10.00	.....	15.00
Winzes	8.00	.....	9.00
4 short winzes 4 x 1 = ...	4.00		
		Central drift (c, fig. 9)	15.00
		Cutting of the barrier pillars near the drift S -- 5 x 1 = ..	5.00
Total	22.00	Total	44.00
Amount of Ore Obtained per Sagene of Preparatory Development			
$\frac{160.00}{22}$ = about 7.3 cu. sag.		$\frac{270.00}{44}$ = 6.0 cu. sag.	

The overhand stoping system is shown to be more economical than the pillar system. Some other advantages of the overhand system as compared with the pillar system are as follows:

1. The breaking of the ore and the filling of the empty spaces is accomplished at the same time and without interruption; this makes the organization of the work in the whole mine more uniform.

2. The stope is ventilated continually; thus safety is increased.

3. The miners in the stope always have two exits, to the upper and lower drifts; in the pillar system there is only one exit to the winze, which is in the layers of the upper sublevel, beginning from the second or third.

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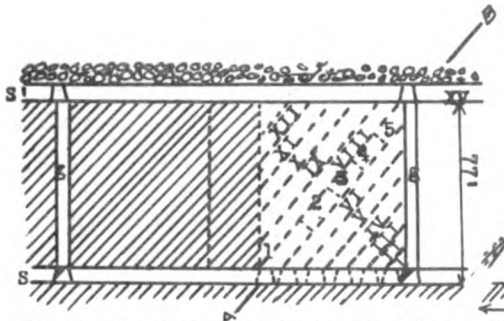

Figure 11.-Method of inclined slices

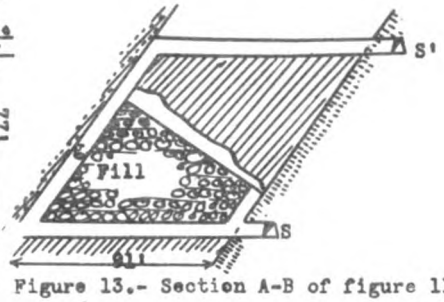

Figure 13.- Section A-B of figure 11.

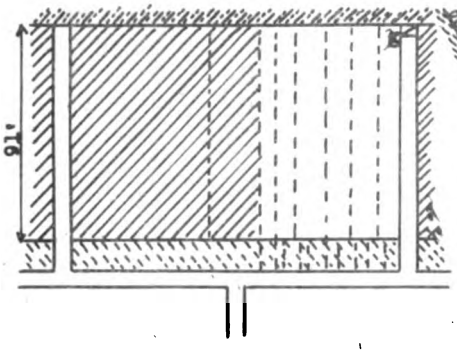

Figure 12.- Plan showing method of inclined slices.

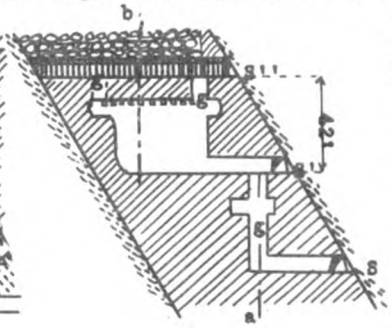

Figure 14.- Chamber system of mining

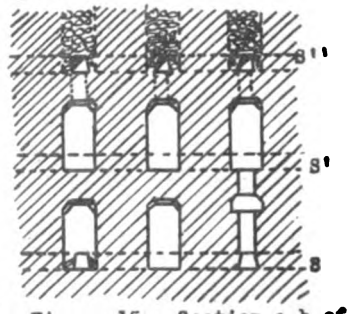

Figure 15.- Section a-b of figure 14.

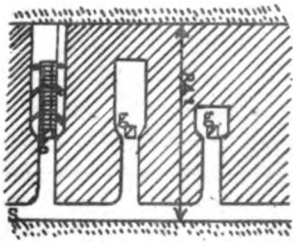

Figure 16.- Plan of level chamber system.

Figure 17.-Plan showing mining of roof pillars.

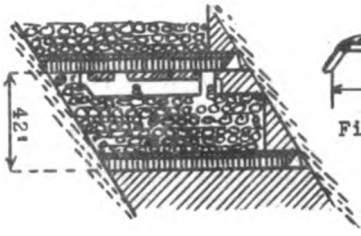

Figure 18.- Mining roof pillars

Figure 21.- Timbering backs of chambers.

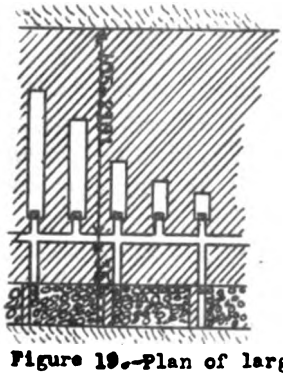

Figure 19.-Plan of large chambers, Karnavatsk mine.

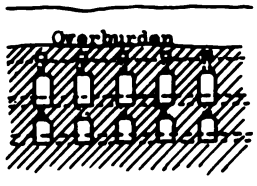

Figure 20.- Section of large chambers, Karnavatsk mine.

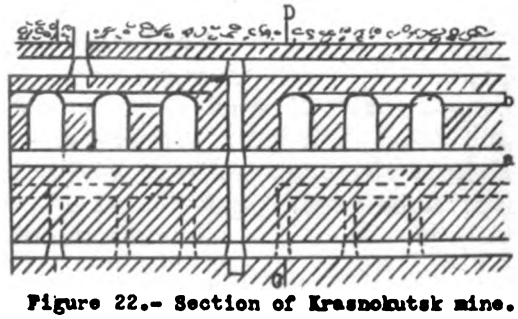

Figure 22.- Section of Krasnokutsk mine.

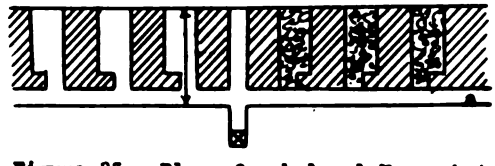

Figure 23.- Plan of sub level, Krasnokutsk mine.

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4. The stopes of the overhand system are always ventilated by the passing current of air; in the pillar system the stopes remain blind until the slices are cut through to the upper drifts.

The disadvantage of the overhand stoping method, or more correctly, the condition of its use, is that wall rocks must be more or less stable.

B. Systems of Mining Ore Deposits of Great Thickness

Several systems alone or in combination are used for mining ore deposits of great thickness, as follows:

Chamber system - system of large chambers;
Transverse level system - perpendicular to the strike of the ore deposit;
Level system along the strike of the ore deposit;
Chamber-trench system;
Chamber system (shrinkage system) with storing of ore, or the magasinbrytning (Swedish) system;
Cover caving system, or the rasbrytning system (Swedish).

1. Removing the Ore by Inclined Slices. - Among the systems used for mining ore bodies of great thickness the system of overhand stoping in which the ore is removed by successive inclined slices is of special note.

This system was used in one of the sections of the Saksagansk mine. Correctly speaking, it is a combination of the overhand stoping system and the transverse level system (perpendicular to the strike). This variation of the overhand stoping system was adopted at the mine because of the necessity of working in the barrier pillar bordering the railway line and because of the sinking of the roof pillars. The system can be called that of "overhand stoping, removing ore by inclined transverse stopes."

At the Saksagansk mine an ore deposit about 91 feet thick with a dip of about 55° was to be mined for approximately 175 feet along the strike of the deposit. In the quartzites of the footwall, at a distance of from 14 to 21 feet from the ore, there were drifts on the fifteenth and sixteenth levels (the height of the sixteenth level was 77 feet). The work was started 17.5 feet from the border. An area 147 feet long was obtained which was divided into two mining sections (figs. 11, 12, 13) by a barrier pillar 21 feet thick, the ore of which was lost because of the special conditions of the work.

The first cross drifts to the hanging wall were driven from the upper and lower drifts. From the cross drift at the hanging wall a connection was made by means of the winze, g, through the ore body to the cross drift of the fifteenth level. The filling material was delivered through the upper drift and the cross drift to the stopes by means of a winze. A slice of ore 7 by 7 feet was taken across the ore and was filled. Then another cross drift was driven close to the first one and a 7-foot slice of the ore parallel to the first slice was taken out

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(fig. 11). As the filling material was a mixture of clay with quartzite, its angle of repose was about 40°; thus the slices formed an angle of from 40 to 50° with the line of the strike. The chute for the filling was covered with 2-inch boards, which were moved as mining progressed.

Mining by taking out the ore in sloping slices is shown in Figure 13. When the mining of the rills was completed, the whole layer, as well as the cross-drift, was filled, and a temporary winze for communication and for passing the ore was left at the footwall.

To decrease the area of the opened ore still more, the mining was divided into two periods; during the first period the lower part of the layer was taken out and the space was filled; during the second period the work was done in the upper part.

In consideration of the fact that the surfaces exposed were not large and that the stopes were continuously ventilated, mining in transverse rills, with which the effect of wall-rock pressure is different from its effect with the usual system, was accomplished without special support; single stulls were used where necessary.

One disadvantage of the overhand stoping system is the necessity of building winzes in the ore body for every layer besides having temporary winzes for every layer also.

From the description of this method of using the overhand stoping system, it is apparent that combinations of different systems can be employed in mining the iron ore. The method described is not presented as a special system, and we have mentioned it only as a particular application which, as far as known, was used in only one mine.

2. The Chamber System of Mining (System of Large Chambers). - This system was used without combination with any other system in the Dubovaya Balka, Karnavatsk, and Bojedarovsk mines, and with slight changes in the Krasnokutsk mine.

In the Dubovaya Balka mine this system was used for about 12 years and was then abandoned.

The thickness of the ore at the Dubovaya Balka mine varied from 7 to 140 feet, but was usually about 70 feet; the angle of dip was from 45 to 55°; the ore was of medium tenacity; the footwall was of stable rocks and the hanging wall of less stable quartzites.

The interval between the levels was 42 feet. The main drifts were driven in the ore close to the hanging wall because the breaking of the ore when mining the chambers toward the footwall is very productive.

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The chambers (14 ft. wide) and the barrier pillars between the chambers (21 ft. wide) were marked along the drift. Cross drifts from 21 to 35 feet long and 7 by 7 feet in cross section were opened along the axis of the chamber so that the vertical winzes driven from them near the stope would come out in the corresponding cross drifts of the upper level (fig. 14).

The winzes were driven vertically because of the instability of the hanging wall rocks, to obtain shorter length, and for convenience in dropping the filling. Also the winze comes out at a very convenient place in the drift of the upper level, which is usually not overloaded with cars. For convenience in moving the cars the cross drifts leading from the drifts were curved a little in the direction of the hoisting shaft.

At a height of from 10.5 to 25.9 feet from the bottom of the level, cross-drifts were opened from the winzes toward the hanging wall and the footwall. To make them stand better, the roofs of these cross drifts were arched; as the drifts were advanced, the roof was reenforced by special "arched" or "English" stulls, which are ordinary shaft stulls with short props 20 to 24 inches long blocked up into the side walls of the chamber (fig. 15) at intervals of from 16 to 24 inches; the stulls were lagged from above and wedged. Owing to the arched form of the roof, this kind of reenforcement was not designed to resist the pressure of the roof mass (9.1 to 10.5 feet) but only to protect the workmen from falling pieces of ore. The stull often holds out without being changed during the entire mining of the chamber.

During the advance of the cross drift the bench is taken out by underhand stoping, using steep, almost vertical holes. After the chamber is worked out in this way to the footwall, mining is started toward the hanging wall.

For filling the chamber another winze is sunk in the roof barrier pillar, and the cross drift along the axis of the chamber which serves for the delivery of the filling material into the chamber of the lower level, is timbered with drift stulls.

A semiwet filling was used in the Dubovaya Balka mine; that is, every 16-inch layer of the filling material was watered. The process of filling one single chamber required about three weeks, but following this, the period of shrinkage took over six months. The empty space formed at the roof of the chamber in the course of the shrinkage was filled again and tamped. Pure clay was preferred for use as filling material, as the quality of the wet filling was lowered by admixtur of quartzite.

After the shrinkage of the filling, the roof barrier pillars, as well as those left between the chambers, could be taken out. The long period necessary for filling and shrinkage (from eight to nine months), the small productivity of the methods used in mining the barrier pillars, and other reasons caused the excavation of the barrier pillars in the Dubovaya Balka mine to be very much behind the mining of the chambers.

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Many methods were tried for mining the barrier pillars, but only recently, by using the rasbrytning system, have satisfactory results been obtained. The roof barrier pillars had previously been worked by the method shown in Figures 17 and 18, in which the cross drift, a, 7 x 7 feet in cross section above the filling passed from the hanging wall to the footwall. The part which was above the chamber and the part above the cross drift, a, were taken away by working backward in sections from 10 to 14 feet long. Sometimes the direct cover-caving system was used, but it is no longer employed on account of the danger.

Many trials were made of methods for mining the barrier pillars left between the chambers. Formerly the barrier pillars were taken out from under the filling by the crosscut method, working downward by using winzes, drifts, etc., but owing to the high expense of artificial support, the winzes and drifts are now driven near the ore body. As mining from above downward is not rapid enough, the rasbrytning method is now generally used. (fig. 100). Owing to the lack of experience in using this system in mining weak ore the height of the slices employed is 14 feet.

The Karnavatsk mine used the system of large chambers for the mining of a large part of deposit 7 from the 140 to 150 foot levels (figs. 19 and 20). Here the thickness was about 350 feet. One 35-foot section near the hanging wall was removed by means of the crosscut system; the next 35-foot section was left temporarily for safety until the third section was excavated; the third section was removed by the system of large chambers. The chambers, which were 14 feet wide, 28 feet high, and 245 feet long, were mined by a method similar to that used in the Dubovaya Balka mine. The method of timbering is shown in Figure 21. Dry filling was used in the chamber; for bringing the filling material in and for ventilation two additional winzes along the length of the chamber were provided. This system was later abandonned because the dry filling was not sufficiently compact even after a long period and because it was difficult to bring water for the semiwet filling.

For mining the barrier pillars (21 ft.) the system of vertical slices and the rasbrytning system were tried. Owing to the great thickness of the ore body the mining of the barrier pillars was very difficult; therefore, in order to increase the safety and the productivity of the work in pillars, the ore deposit was divided into three parts, of 70 feet, 70 feet, and 105 feet (see fig. 91 of the 210/140-foot level), by using the chamber-trench method. The trials were not concluded.

The Bojedarovsk mine has used the system of large chambers to mine an ore deposit about 56 feet thick (varies from 14 to 120 ft.) with an angle of dip of from 60 to 70°. Here the chambers were also 14 feet, the barrier pillars 21 feet, the height 28 feet, and the level interval 35 feet. Semiwet filling was used. The barrier pillars were mined by the crosscut method, which is characteristic of this mine. Drifts along the hanging and footwalls were driven first, then winzes were run up to the level above, from which the mining was started by slices downward.

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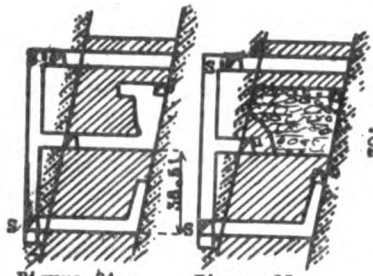

Figure 24.- Figure 25.-
Sections of Krasnokutsk mine.

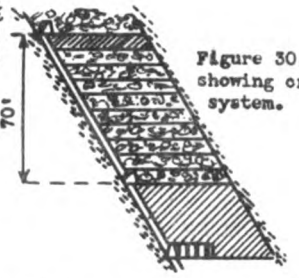

Figure 30.- Section showing cross cut system.

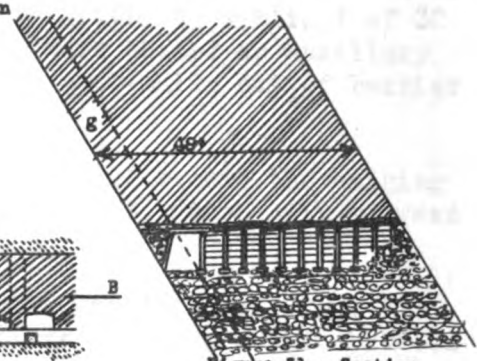

Figure 31.- Section A-B of figure 32.

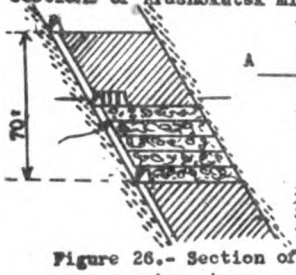

Figure 26.- Section of cross cut system.

Figure 27.- Plan of cross cut system.

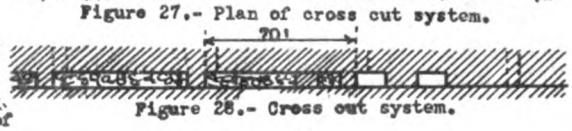

Figure 28.- Cross cut system.

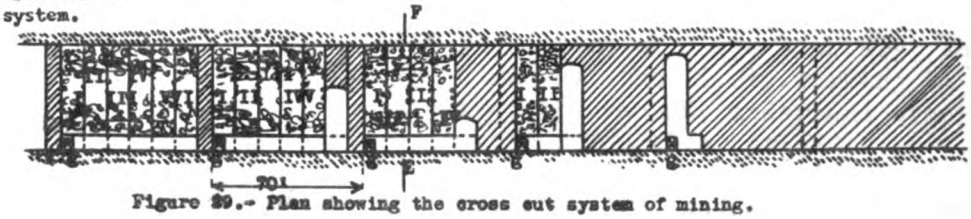

Figure 29.- Plan showing the cross cut system of mining.

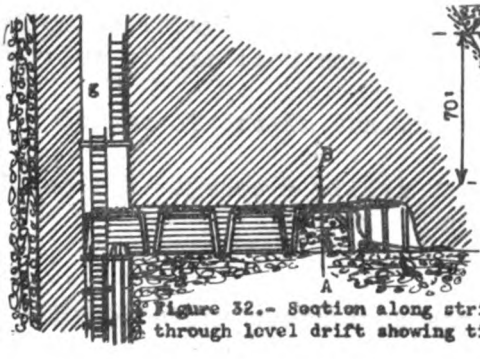

Figure 32.- Section along strike through level drift showing timbering.

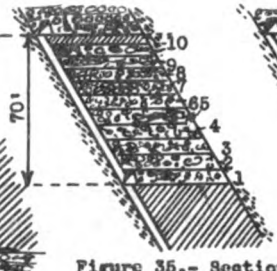

Figure 35.- Section showing shrinkage of filling

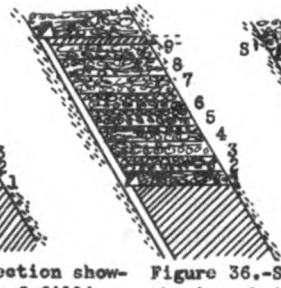

Figure 36.-Section showing shrinkage of filling.

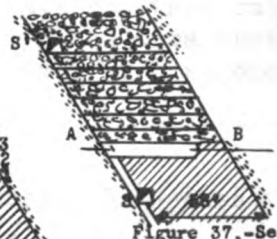

Figure 37,-Section showing mining from top downward.

Figure 33.- Figure 34.-
Showing details of timbering.

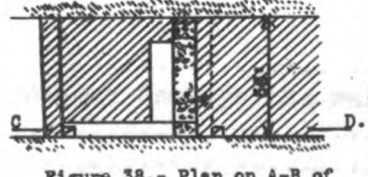

Figure 38.- Plan on A-B of figure 37.

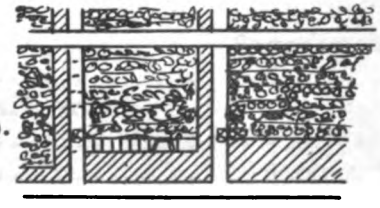

Figure 39.- Vertical projection on C-D of figure 38.

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The system of large chambers was used with little variation at the Krasnokutsk mine to mine a deposit about 42 feet thick with an angle of dip of from 80 to 90°. Here (figs. 22, 23, 24, and 25) the level interval was 77 feet and was divided by a central drift into two sublevels, each 38.5 feet high. The main drifts were placed in the hanging wall and the central drifts in the ore near the hanging wall. After driving cross drifts from the drifts through the ore body, to the footwall at 21-foot intervals, raises were driven to a height of 32 feet; from them at a height of 24.5 feet, gangways, b, were opened as auxiliary drifts (fig. 25) which served for filling, ventilation, and taking out of barrier pillars.

By breaking out stopes 14 feet wide from the footwall toward the hanging wall, a barrier pillar of ore was left near the central drift. Such pillars were to be taken out later.

After filling the chambers (the filling material was delivered from the bottom of the quarry through a winze) the barrier pillars which were left between the chambers were taken out as soon as the filling became compact, using the same system as for mining the chambers. The roof barrier pillars, 7 feet thick, were to be taken out after those left between the chambers, if possible, by the method of vertical slices.

Apparently, from the description of the system of large chambers, the breaking of the ore may be divided into two periods: the first, working by means of a 14-foot cross drift is not very productive; the second, underhand stoping of the 14-foot thick sloping brow of the ore, is the productive period.

The coefficient of economy of the chamber system, under average conditions, is as follows:

Thickness, 10 sagenes; angle of dip, from 60 to 70°; ore and wall rocks of medium solidity and tenacity. The chamber is 2 sagenes wide and 4 sagenes high, the barrier pillar is 3 sagenes wide, and the height of the level is 5 sagenes.

Volume of ore in the mining section:

Chamber 2 sagenes + pillar 3 sagenes x thickness 10 sagenes x 5 sagenes =
5 x 10 x 5 = 250 cubic sagenes.

Preparatory operations and stope development per section:

	Sagenes
The drift	5.00
The cross drift--entrance into the chamber through the wall rocks and ore	about 7.00
The winze from the cross drift	5.00
The front cross drift of the chamber	10.00
The winze for the filling material at the end of the chamber	1.00
	28.00

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For mining the barrier pillars by the rasbrytning method in slices of 3, 3.5, and 3.5 sagenes:

	Sagenes
The winze on the center of the barrier	5.00
Three crosscuts to the ore, 3 sagenes each	9.00
Three cross drifts, 10 sagenes each	30.00
	44.00
Total	28.00 + 44.00 = 72.00

Per 1 sagene of preparatory work:

$$\frac{250 \text{ cubic sagenes}}{72 \text{ sag.}} = \text{about } 3.5 \text{ cubic sagenes of ore.}$$

Here the operations by which the economy of the method is decreased are the following: Mining the chamber--the work of the front cross drift of the chamber; mining the barrier pillars--the preparatory work necessary for each layer. The cost of taking out the barrier pillars can be considerably reduced by increasing the thickness of the slices.

The following disadvantages of the system may be mentioned also:

1. The difficulty of filling the great empty spaces of the chamber, especially the necessity of transporting the material inside of the chamber;

2. The necessity of using the semiwet filling, which increases the cost of the work considerably;

3. The long period necessary for complete shrinkage of the filling, which delays removal of the barrier pillars.

Dry filling, as adapted in the Karnavatsk mine, may be accomplished simultaneously with the mining of the chamber, but the time necessary for the shrinkage of the filling is reduced only a little; besides it is not certain that the filling will become monolithic.

The advantage consists in the possibility of starting a great number of stopes, and in a considerable productivity from the robbing operations. Owing to a small coefficient of economy, the system of large chambers has not been used much in the mines of the region and remains in use only at the Bojedarovsk and Krasnokutsk mines.

3. Crosscut system; removing the ore by slices (the level system). - This system is the oldest in the region. Its sphere of use is very large and it is employed for mining ore deposits of small as well as great thickness, of solid as well as weak ores, and of solid as well as weak wall rocks. This system is flexible and can be used, with slight changes, for mining any ore deposit.

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(a) Crosscut system: Removing the ore by slices in a direction perpendicular to the strike of the deposit (transverse level system)

This system is used in the Karnavatsk mine, in medium hard and solid ore deposits from 35 to 49 feet thick, generally without combination with any other system. The level interval is usually 70 feet. The level drifts are usually driven near the footwall; the lower serves for tramming ore and the upper for movement of the filling material (fig. 26).

The mining area is divided along the strike of the ore deposit into 70-foot sections between which temporary barrier pillars 7 to 10 feet thick are left, these barriers end at the top and the bottom of the levels, as well as at the hanging and foot walls of the deposit. An inclined winze (5.6 by 4.2 feet) leading to the filling drift is usually driven through the barrier pillars (fig. 26). At the same time, cross drifts from 8.6 to 14 feet wide and 7 to 7.7 feet high are started toward the hanging wall (a, fig. 27; fig. 28). After the cross drifts have reached the hanging wall at the border of the temporary pillars (a^1, fig. 27) left between the cross drifts, vertical sets lined with 1-inch boards are erected 3.5 to 4.5 feet apart, and the space is filled with a mixture of clay and small pieces of quartzite; the latter are delivered through the filling winzes or through the shafts, using the tramming drifts. After the filling and closing of the cross drifts from the side of the drift by stulls, the barrier pillars (two) left between the cross drifts are taken out.

After the completion of the mining and filling of the 7-foot horizontal slice of ore, limited by the vertical barrier pillars and by the drift and hanging wall of the deposit, the drift within the limits of the section must be well supported, less strongly at the barrier pillars and more strongly at other places.

In the winze already constructed at this time, a hatch is made and a cross drift towards the hanging wall is driven from the winze on the second slice. The cross drift is used as a stope 10 feet wide and 8 feet high; the work is done standing on the filling of the first slice. This first cross drift of the second slice (fig. 29) is reenforced by from 2 to 6 sets spaced at intervals of 7 feet, depending on the solidity of the ore; sometimes cross braces are put between the sets, which are on pieces of sill timber 2 to 2.5 feet long, laid in the direction of the horizontal axis of the cross drift (figs. 30, 32, 33, and 34). After the hanging wall is reached the cross drift is prepared for filling; laths are nailed at the corners of the sets, and the main set (the "chamber" set) is erected at the beginning of the cross drift near the winze. The laths (fig. 34) are nailed to help them withstand the pressure of the filling against the lateral props. The side which is turned toward the cross drift is lined with boards and the cross drift is filled from the winze by the material obtained through the filling drift of the given level, which is the tramming drift of the upper level.

After the filling of the first workings and the separation from the winze is completed, a second cross drift 10.5 feet wide is opened above the lower drift; the stope of this cross drift is already cut from three sides - from the front, from beneath, and from the side of the first cross drift.

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There are six such workings in the second slice (63 ft. of the mining section between the barrier pillars are divided by 10-foot cross drifts).

The drift of the second slice (the so-called level drift), which is formed by the cuts for mining the stopes, is supported by double sets erected along its length or by chamber "hooks", as well as by sets placed about here and there. During the timbering, cross pieces or sprags are placed between the sets in order to prevent the falling of the sets during the blasting of the holes, and foot pieces under the props of the sets are also used (figs. 31 and 32).

After the last stope near the barrier pillar is mined it must be filled. After the second slice (second 7-ft. thick horizontal slice of ore) is filled, access to the third slice is accomplished by means of a winze; a ladder road and chute for the ore with an opening towards the drift is arranged. Thus the stoping is accomplished by mining 7-foot slices until the upper level is reached; a barrier pillar from 3.5 to 6.3 feet thick, depending on the solidity of the ore, is left. As the vertical height of the level is 70 feet and the height of the slices is from 7.7 to 10.85 feet, there will be nine slices.

Since during the rise of the stope the filling upon which the workmen stand shrinks further and additional filling becomes necessary, the standard height can not be adhered to for the upper slices; it becomes necessary either to keep the normal height of the slices, thus finally to have 10 slices, or to increase the height of the slices, beginning with the sixth slice (figs. 35 and 36). The roof barrier pillar usually can not be taken out.

The timber of each slice is used for working the slice above it; the props are taken out by picks or special hand tools. For tramming the ore, light rails (3.17 lbs. per ft.) are laid and the cars used are either of the Koppel type or are wooden cars reenforced with iron. The vertical barrier pillars left near the winzes can sometimes be taken out after the end of the work on the levels; they may be removed by working from above downward, using the same system of horizontal slices. Generally, however, these barriers are at that time already crushed and can not be taken out. Only about 30 or 40 per cent of them can be recovered. If the hanging wall consists of weak rocks, a certain amount of the ore near the wall can not be removed.

If the ore of a certain section is very weak, the same crosscut method is used, but the mining of the slices is accomplished from above downward, and the mining of the workings is started preferably from the border of the section and retreats towards the winze.

By mining from above downward the composition of the filling mixture must always be the same; usually not more than 30 per cent of sand or small pieces of quartzite is used. As the disadvantage of this system lies in the impossibility of recovering the used timber, special care must taken and as many sets as possible removing during the filling. A scheme showing mining performed from above downward is given in Figures 37, 38, and 39.

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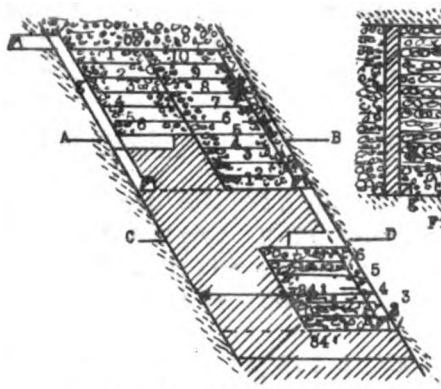

Figure 40.- Showing combination method.

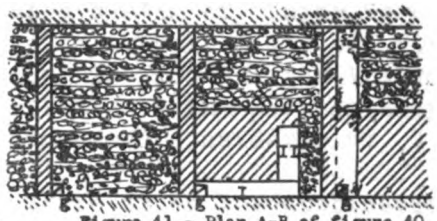

Figure 41.- Plan A-B of figure 40 combination method.

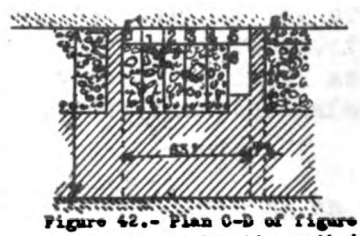

Figure 42.- Plan C-D of figure 40 combination method.

Figure 43.-

Figure 44.-

Figure 45.-

Figures 43,44,45, show working from below upward.

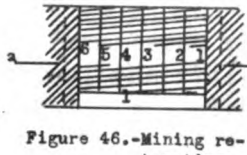

Figure 46.-Mining retreating.

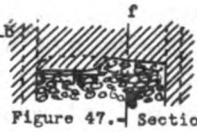

Figure 47.- Section a-b of figure 46

Figure 48.-Section of figure 47.

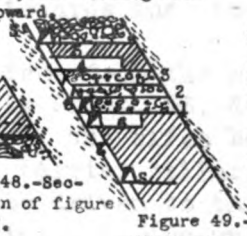

Figure 49.- Mining from above downward.

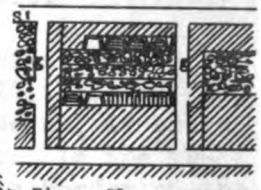

Figure 50.- Longitudinal projection, figure 49

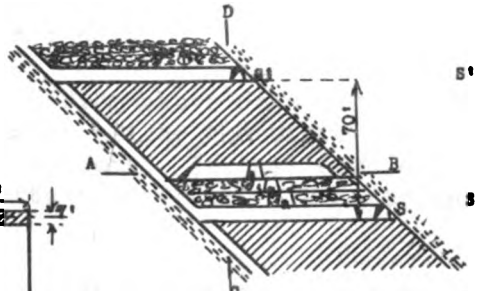

Figure 52.- Section E-F of figure 53.

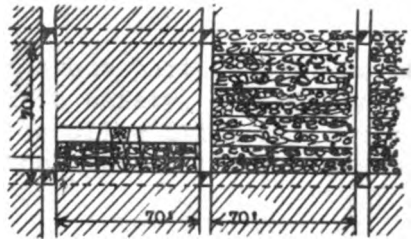

Figure 54.- Section C-D of figure 52.

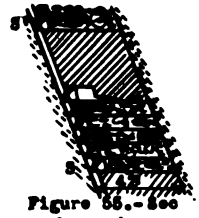

Figure 55.- Sec Rudner mine.

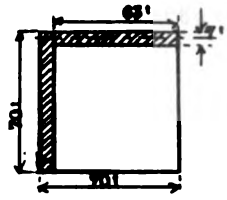

Figure 51.- Showing proportion of ore lost in pillar.

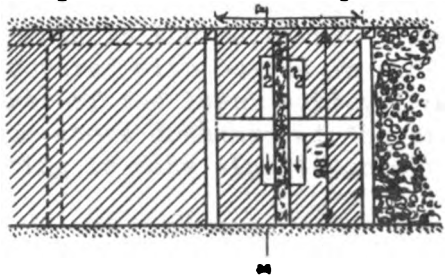

Figure 53.- Plan A-B of figure 52.

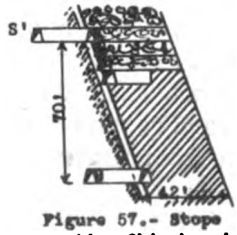

Figure 57.- Stope section Shireky mine

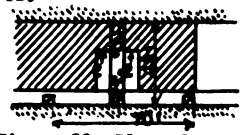

Figure 56.- Plan of Rudner mine method.

Figure 58.- Plan of stope, Shireky mine.

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The disadvantage of the crosscut system, where there are level drifts inside the ore body near the footwall, lies in the loss of the ore in the roof barrier pillars. At present the system of driving drifts through the wall rocks is used, thus making complete extraction of the ore possible.

For mining ore deposits of great thickness or those having thin layers of soft, friable ore, the combination system of mining is used; one part of the ore is taken from above downward and the other, after the first work is finished, from below upward. The order of mining is from the hanging wall toward the foot, as in this case the pressure is distributed on the part already filled; thus the safety in mining the next section is increased considerably.

In Figures 40, 41, and 42 is shown the combination method of mining an ore deposit 84 feet thick. Here the preparation consists of driving the lower drift on the footwall and the upper drift through the barren rocks of the footwall and of the winzes near the footwall.

The mining in layers in both cases - that is, either from below upward or from above downward - may be accomplished by advancing either from the winze towards the border of the section or from the border towards the winze.

In working from below upward by removing slices from the winze to the border of the section, the slices are mined gradually (figs. 43, 44, and 45), and the other area of the ore, which is cut by the roof of the slice below, is solid with supports in the wall rocks and in the vertical barrier pillar. In the reverse order of working, the slice drift must first be driven to the border of the barrier pillar and then timbered, after which the mining is accomplished by moving backward (figs. 46, 47, 48). If this plan is followed, the whole ore body on the given level is cut near the footwall and thus is deprived of its main support (fig. 44, section c-d).

In working from above downward the dangerous part of the operation is the filling of the upper slice; therefore, to work in safety, the mining must be started from the borders. In this case only the slice drift may cause trouble; all the other parts of the work are safe, as the upper filling rests on the solid ore.

Where the ore is weak the level is divided into two sublevels each 35 feet apart vertically. First the upper sublevel is mined from below upward, and then, the lower sublevel is mined in the same way. The ground of the first layer of the upper sublevel is covered with boards in order that the filling during the mining of the upper layer of the lower sublevel may not fall from the roof. The mining is also done from above downward if the ore is weak (figs. 49 and 50). Levels in which the mining is done simultaneously are arranged as shown in Figure 40.

As mentioned previously, in using the crosscut system at the Karnavatsk mine the ore of the barrier pillars near the winzes, as well as that of the tenth slice, was almost always lost. Therefore part of the ore of the mining section between two winzes was lost.

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The area of the ore of the section close to the footwall rocks is equal to: 10 x 10 sagenes[5] = 100 square sagenes. The loss of the ore in the barrier pillar near the winze is: 10 x 1 = 10 square sagenes, or $\frac{10}{100}$ = 0.10; that is, 10 per cent.

The loss of the ore in the tenth slice is: 9 x (1 -0.50) = 9.00 - 4.50 square sagenes or $\frac{9.00 - 4.50}{100}$ = 0.09 - 0.045; that is, 9 to 4.5 per cent.

The total loss is therefore: 10 + (9 - 4.5) = 14.5 per cent.

To reduce the losses of ore in the vertical barrier pillars, one of the following two methods was used: (1) The width of these barrier pillars was increased and they were taken out later by mining from above downward; (2) the barrier pillars were not left within the section at all, and only the region barrier pillars, at intervals of 210 to 280 feet along the strike of the ore, were left near the so-called main winzes and made thicker for mining from above at the time of the closure of the level.

The first method was used in many mines and satisfactory results were obtained: barrier pillars even 14 feet thick could be taken out entirely. A more sturdy construction of the winzes was used or they were continuously repaired to preserve them until the closing of the level.

In the Rakhmanov mine the system was changed in accordance with the second method. Due to the great thickness of the ore body (more than 70 ft.) the slice drift was driven almost through its center (figs. 52, 53, and 54) along the strike, and from this drift stopes were opened as shown by the numbers given in the figures.

The working of the next series was started after the filling of the previous stope and the corresponding parts of the slice drift was completed; that is, the stoping of the ore was done by using two neighboring winzes. The mining was done from below upward. Barrier pillars from 23 to 35 feet thick were left at every 175 feet to 210 feet along the strike of the ore; they were taken out at the closing of the level by working from above downward.

The same method of mining from the center of the section was used under similar conditions at the Rudner mine (figs. 55 and 56) and by the Shiroky mine (figs. 57 and 58), but owing to the friability of the ore and weakness of the footwall in the Shiroky mine the maintenance of the winzes in the filling was difficult, so that the chamber-trench system was used instead. An interesting application of the second method was used in the Polevoy mine for working a bowlder brown iron ore deposit from 7 to 21 feet thick and with weak wall rocks; the hanging wall was green clay and the footwall was sedimentary slate. Owing to the weakly cemented condition of the ore as well as of the wall rocks, mining was done from above downward. From the lower tramming drift, p, (figs. 59 and 61) inclined raises, c, c, were driven, and from them the upper drifts, D, were mined. The upper and lower drifts were connected every 350 feet by inclined raises, c, c, having compartments for the lowering and raising of cars. Sections between the inclined

5 One sagene is equal to 7 feet.

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Figures 59-60-61.- Showing mining from above downward at the Polevoy mine.

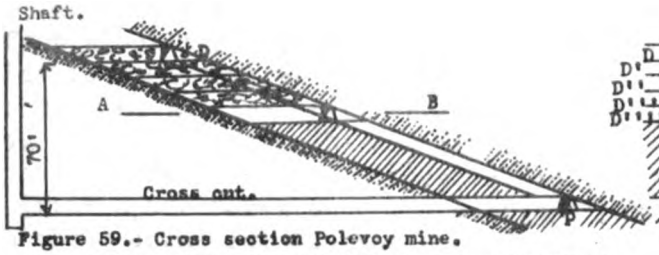


Figure 59.- Cross section Polevoy mine.

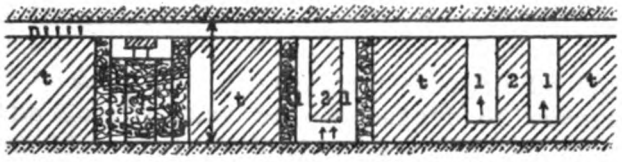
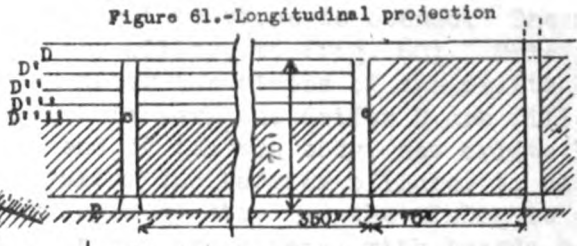


Figure 60.- Plan on A-B of figure 59.

Figure 61.-Longitudinal projection



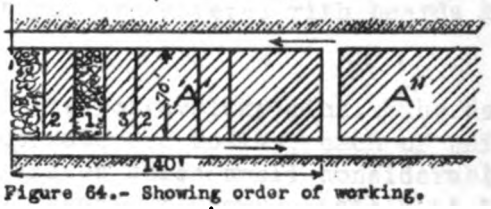


Figure 64.- Showing order of working.

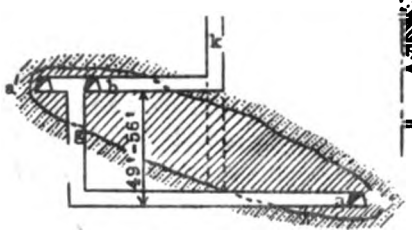


Figure 62.- Section showing mining of small ore bodies.

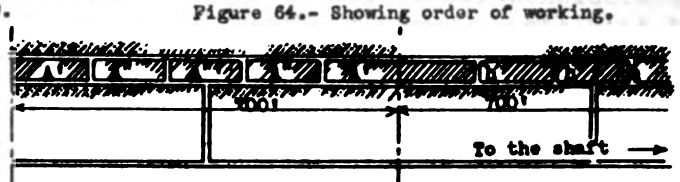


Figure 63.- Plan showing the mining of small ore bodies.

Figures 65 and 66 show mining from top downward at the Ergenier mine.

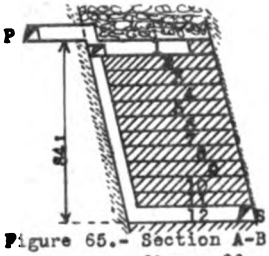


Figure 65.- Section A-B of figure 66.

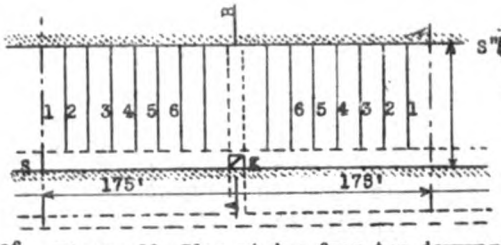


Figure 66.-Plan, mining from top downward

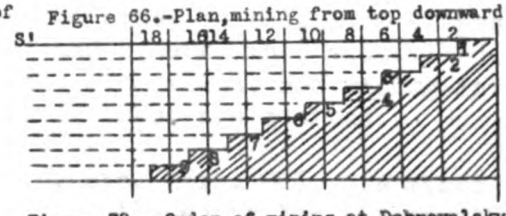


Figure 70.- Order of mining at Dobrovalsky mine.

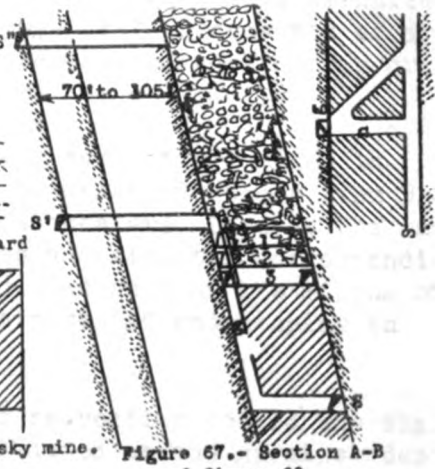


Figure 67.- Section A-B of figure 68.

Figure 69.- Section along level S.

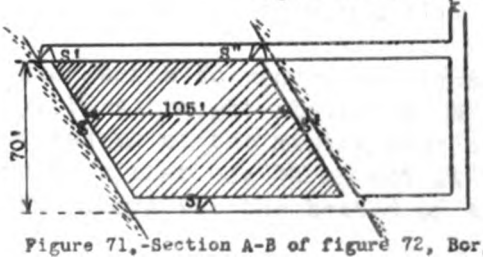


Figure 71.-Section A-B of figure 72, Borjedarov mine.

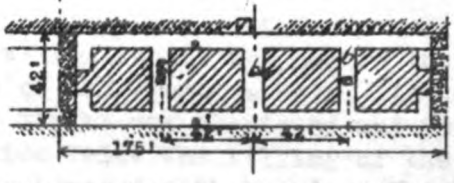


Figure 68.-Plan of method at Dobrovalsky mine.

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planes can be mined independently one from another. After the stope from the drifts, D, is sufficiently advanced, panels 42 feet long are laid out which are mined by cross drifts 14 feet wide. The ore is worked by two stopes at the same time, and after they are filled, a third intermediate stope is opened. The next 42 feet along the strike is left as a temporary pillar, t, (fig. 60). This pillar is taken out by the retreating system after the stopes of the drifts D have reached the end of the ore body; during this work the drifts D are filled also. When the drifts D' are closed to the end of the ore body, new drifts D are opened from the inclined planes, c, so that after the barrier pillars, t, along the drift D are taken out, the drifts D" are opened; etc. As the mining is done from above downward, the bottoms of all the stopes are covered with boards before filling.

Another interesting example is that of the Dobrovolsky mine. The deposit of the Dobrovolsky mine consists of several separate ore bodies, each of which is mined separately. Wall rocks consist of clay slates which swell considerably if watered. Each ore body is opened by a vertical shaft, k, approximately at the center and at its deepest part (fig. 62). The preparation of the deposit for mining is accomplished by driving two upper tramming drifts, a' and b, and one lower drift, a, in both directions from the shaft. The height of the level is from 42 to 70 feet. The drifts are connected by inclined gangways. The whole ore body is divided into several sections from which the ore is mined independently.

From the main drifts (A', A", fig. 63) cross drifts are driven toward the centers of the sections; from these cross drifts, winzes (g, fig. 62) are driven to the level of the upper drift. The mining of each section is accomplished by beginning at the border and working toward the center in which the chute-winze as well as the mouth of the filling hole (k, fig. 62) is situated. The mining is done from above downward. The stope preparation consists of driving cross drifts (h, fig. 63) at 140 to 175 foot intervals connecting the drifts, a' and b.

The parts A', A", A"', etc. (fig. 63), of the section are mined in numerical order from the boundaries of the section by means of stopes from 9.31 to 14 feet wide and from 7 to 9.31 feet high. Two stopes are mined at the same time. Figure 64 shows the order in which the stopes and also the corresponding parts of the drifts, a' and b, are mined and filled. As soon as the mining of parts A' is finished they are filled, and mining in parts A" and stoping in parts A' of the next lower level are started.

Sections 1, 2, 3, etc. (fig. 64), are mined retreating toward the shaft; in the sections remote from the shaft the slices situated at the greatest depth below the upper drift are mined first.

The desire to reduce or eliminate entirely the loss of the ore in the barrier pillars brought about the use of a number of different methods. In some mines the length of the mining sections along the strike was shortened and the roof barrier pillar was taken out as the tenth slice below the filling of the level lying above it; the bottom of this level was covered with boards. The loss

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of ore in the vertical barrier pillars increased, however, owing to their large number. Removing the roof pillars under the filling of the level became dangerous owing to the failure of the timber during the long period before the levels can be closed. Therefore mining by the use of sublevels was adopted, as the period necessary for taking out the upper layers of each sublevel could then be shortened (figs. 49, 50). Notwithstanding this, a loss of the vertical barrier pillars is possible.

The main reason the complete mining of the ore is difficult when the crosscut system is used is that the upper filling drift must be maintained during the whole period of operation. Efforts are made to obtain the least possible loss of barrier pillars and are entirely safe upper drift at the same time. If possible, therefore, the drifts are driven through the barren rocks of the footwall or, if the rocks are very strong, through the ore body by entering along the footwall only; in the latter procedure it is sometimes advisable to leave a small pillar of ore under the drift (in case of a slightly dipping ore body). This can not be considered very good practice as in addition to the loss of the barrier pillar, safety of the drift is only partly obtained.

If the conditions for supporting the drifts by means of regional barrier pillars are not satisfactory, the only safe method is that of driving the field drifts through the wall rocks. The high cost of these field drifts is usually compensated for by the small amount of timber required. Also, the cost may be reduced by increasing the height of the level.

The Ergenier mine has combined crosscut mining by means of stopes from the borders of the section to the winze, with mining by driving the upper drifts through the barren rocks of the footwall. Here (see figs. 65 and 66) the mining of the levels is from the top downward, under the filling; parallel to the drift, P, through the barren rocks, the drift, S, through the ore body, is driven near the footwall; a roof barrier pillar 1.4 feet thick is left for safety. The first slice is taken from under the filling of the upper level. The stopes are opened from the borders of the section and are driven toward the winzes in the order shown in Figures 65 and 66.

By working from above downward this method gives better results than that used in the Shiroky mine. The driving of the lower tramming drift through the ore, as is done in the Ergenier mine, is not good practice; it would be better to drive the drift through the barren rocks.

In the Dobrovalsky mine the crosscut system is used with slight changes. Here (figs. 67, 68, 69, and 70) the upper filling drift, S, is driven through the rocks of the footwall at a distance of from 70 to 105 feet from the ore body (the thickness of the ore body is 42 ft.). The slates lying between are very weak. Sections 175 feet long are mined by using one main winze, g, in the center of the section driven through the slates of the footwall near the ore body.

The winze is directly connected with the upper crosscut and with the lower tramming crosscut by means of the cross drift (n, fig. 69) in the ore body.

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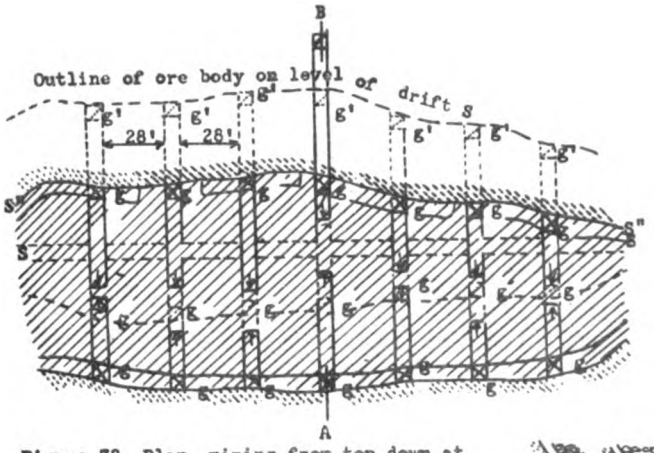

Figure 72. Plan, mining from top down at Bojedarov mine.

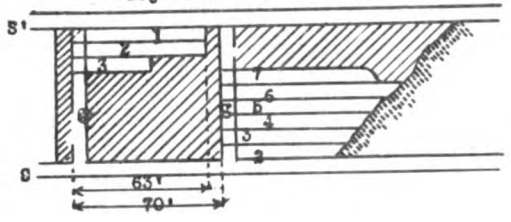

Figure 75.- Longitudinal projection.

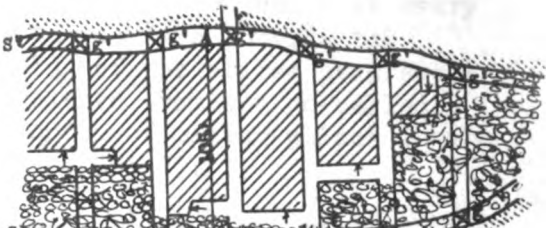

Figure 73.- Plan of mining level, mining from top downward at Bojedarov mine.

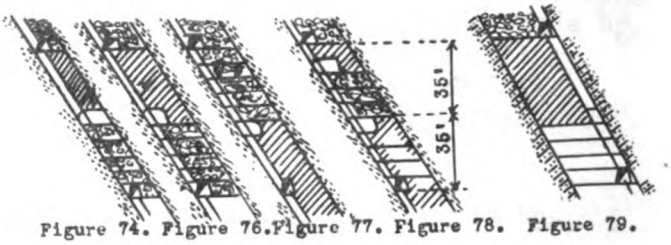

Figure 74. Figure 76. Figure 77. Figure 78. Figure 79.

Figures 74 to 79 inclusive.-Mining by lonitudinal slices from winzes.

Figures 80 to 86 inclusive show mining by longitudinal slices from winzes.

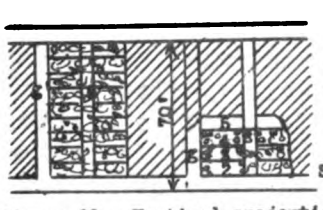

Figure 80.- Vertical projection.

Figure 81.- Plan.

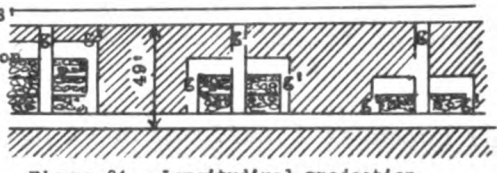

Figure 84.- Longitudinal projection.

Figure 82.-Vertical Section

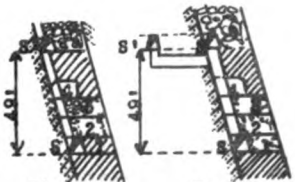

Figure 83. Cross section.

Figure 85. Cross section.

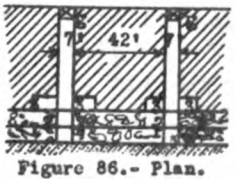

Figure 86.- Plan.

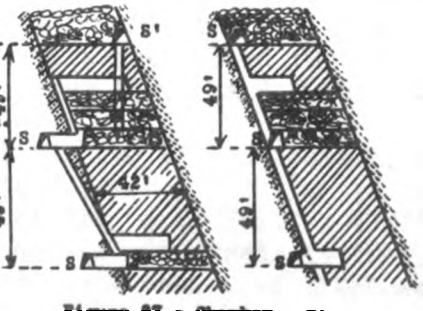

Figure 87.- Chamber-trench system.

Figure 88.-Chamber-trench system.

Figure 89.- Longitudinal section, chamber-trench system.

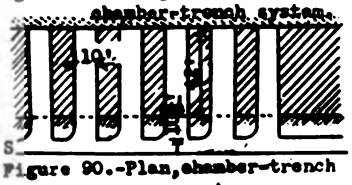

Figure 90.-Plan, chamber-trench system.

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In every slice drifts are driven near the hanging and foot walls through the ore, leaving a roof barrier pillar 2.1 feet thick; the drifts are connected at every 35 feet by cross drifts. The mining proceeds from the borders towards the center. Winzes, g, serve for ventilation. The mining of the slices progresses from above downward under the filling, which is furnished from the so-called mills of the old filling of the upper levels. The order of mining slices in the sections of a whole wing of the deposit is shown in Figure 70.

In all the cases in which the crosscut system was used, the filling material was delivered from other parts of the mine - from the mills, overburden, and filling of the upper levels or from the surface by being lowered down through special winzes and shafts or through the hoisting shafts. The cost of furnishing the filling material in this manner is very high. Therefore the attempt made by the Bojedarov mine to use filling material from nearby places is interesting. Here (figs. 71, 72, 73) the mining of an ore body 105 feet thick and 280 feet long was done from above downward. The levels used in the crosscut method are usually 70 feet apart vertically.

On a given level the development consists of driving a main tramming drift, S, in the center of the ore body on a straight line if possible. Every 28 feet along the strike of the ore, cross drifts 7 feet wide perpendicular to the direction of the main drift are opened toward the hanging and foot walls.

At the ends of the cross drifts raises through the ore body are driven to the upper level. Sometimes the raises at the hanging wall pass outside of the ore body in order not to keep them straight where the dip of the ore body changes. From the tops of the raises, under the filling of the upper level, cross drifts are opened exactly over the lower cross drifts and are connected through the hanging and footwalls. After finishing this work the mining is started either from the hanging or footwwall, depending on the location of the filling hole. It is more logical to start from the hanging wall, as the absence of barrier pillar necessitates the placing of a filling buffer to prevent the falling of the roof.

The mining of the stopes is accomplished as shown in Figure 73 (compare the different methods). The filling is delivered for the three first layers only. The filling must be done carefully and the quantity of material used must be watched; the amount of quartzite in the clay must not be over 30 per cent of the whole mass. After the three layers are filled in this way the other layers are filled with material from the upper layers and upper levels.

This method causes the sinking of considerable areas of the surface. The application of this level system does not require the leaving of roof-barrier pillars; besides, the driving of the upper filling drift becomes unnecessary, as it is replaced by the filling drifts and crosscuts to the sections. The combined influence of two factors, low dip and decreased thickness, makes the application of the method through the whole deposit impossible.

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Special complications in the use of the crosscut method arise where the ore is friable. Thus in the Alexandrovsk, Shirokiy, and Ushakov mines the length of the sections along the strike of the ore was shortened and also divided into sublevels, and the mining of the parts of the sections (Alexandrovskiy and Sukhaya Balka) was done in succession; in some mines (Sukhaya Balka, Shirokiy) this method was to be given up entirely.

The coefficient of economy for the crosscut system used in mining perpendicular to the strike of the ore body, is estimated as follows:

Thickness, 10 sagenes; angle of dip, 60 to 70°; ore body and wall rocks of medium solidity and tenacity.

The mining section: Thickness along the strike of the ore body, 9.00 sagenes + 1.00 sagene; thickness of barrier pillar, 10.00 sagenes; height of the level, 10 sagenes.

Volume of ore in the mining section:

9.00 x 10.00 x 10.00 = 900 cubic sagenes. The barrier is assumed to be lost.

Preparatory operations per section:

	Sagenes
Drift	10.00
Crosscut to the layer, about .	3.00
Drift through the ore	9.00
Winze	10.00
Cross drifts, three per layer, 3 x 9	27.00
Total	59.00

Per 1 sagene of preparatory work:

$$\frac{900}{59} = 15.3 \text{ cubic sagenes.}$$

If a barrier pillar from 1.5 to 2.00 sagenes thick is left and is taken out entirely by the crosscut system working from above downward, or by the rasbrytning system, the volume of the ore will be:

10 x 10 x 10 = 1,000 cubic sagenes!

With the first system there will be no additional preparatory work at all, but the mining will be delayed owing to the work under the filling; with the second system the cost will increase owing to the increase of the cutting-out operations, but, on the other hand, the mining of the barrier pillars will be accomplished much more quickly.

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If three slices are made there will be additional construction work, as follows:

	Sagenes
Winzes in the quartzite	10.
Two crosscuts to the ore body 3 sagenes each .	6
Cross drifts to the barrier pillar	30
Total	46

That is: 59 + 46 = 105 sagenes.

Per 1 sagene of preparatory work:

$$\frac{1000}{105} = \text{about } 9.5 \text{ cubic sagenes.}$$

Thus, notwithstanding such advantages as economy, safety of work, and wider adaptation to different conditions, the crosscut system has one great disadvantage in that even if the rasbrytning system for taking out the barrier pillar can be used, only one mining stope, usually less than 14 feet wide, can be opened on a length of 70 feet along the strike of the ore. If the regular level system is used there are the additional disadvantages of a loss of 10 per cent of the ore if the barrier pillars are 7 feet thick, or a costly, slow, and not very productive operation from above downward if the barrier pillars are thicker.

(b) Crosscut system - excavating the ore in slices along the strike of the ore body (level system along the strike)

Excavation of the ore in slices along the strike of the ore body (used where the thickness of the ore deposit does not exceed 35 feet or in ore which has many cracks and slippery layers) is the system employed, without combination with other systems, at the Karnavatsk, Chervonny and other mines. It is especially convenient where the length of the mining section along the strike is changeable at the borders because of pinching out of the lode or the appearance of quartzite (figs. 74 and 75).

The level drifts in the footwall of the deposit are 70 feet apart vertically. The winzes are opened at 70-foot intervals along the strike of the ore body. Vertical barrier pillars, from 7 to 14 feet thick, are left near the winzes. The first layer is usually excavated by means of cross drifts. The work proceeds upwards to the second layer, and the ore is taken by working along the strike, starting either from the hanging or the footwall, depending on the stability of the ore (fig. 76).

After the first layer is filled, the work is continued in the second layer in the same order as in mining the layers perpendicular to the strike. If the ore is weak, sublevels are used (fig. 78), and where the ore is friable the mining is done from above downward (fig. 77).

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Interesting variations of this system, due to special properties of the ore deposit, are applied in some sections of the Likhmanovsk mine; these variations may not be very logical in some of their details. Here the ore is from 10.5 to 35 feet thick, with a mean thickness of 24.5 feet and an angle of dip of 45 to 80°; the ore is solid red hematite with almost imperceptible cracks, filled with gray talco-chlorite slate, crossing one another at about 60°. This characteristic constitutes a danger, as it may cause premature falls; the ore near the hanging wall is much softer.

The development consists of drifts driven near the hanging wall through a comparatively soft part of the ore body, the level interval being 70 feet. The mining area between the level drifts is cut by winzes (g, figs. 79, 80, 81) at 70-foot intervals.

The mining is accomplished from these winzes and is done in the following manner: At both sides of the winze one slice of the ore is excavated for a length of 21 feet. The ore is mined out at the winze through the whole thickness of the ore body if the thickness is not over 10.5 feet or in layers if thicker; the thickness of each layer depends on the stability of the ore and may be from 7 to 10.5 feet. Where the thickness of the ore body is 31.5 feet, the mining is done in three slices, as shown in Figure 81; the height of the slices is from 7 to 10.5 feet.

The sections are excavated at one side of the winze (see winze 1) or at both sides (winze 2), so that if the ore is taken at one side of the winze the excavation at the other side of it is filled. After the first slice is mined, it is filled, and the excavation of the second slice is started.

After the mining and filling of the second slice is completed, the work on the third is started, and so on.

If the stability of the ore allows it, two slices may be opened simultaneously from the same winze (winze 3). After the first slice is taken, the stoping is raised to the second slice, and the excavation is accomplished over the filling in the same manner. The size of the winze is 7 by 4.62 feet; it is divided into two compartments, one for throwing down the ore and the filling and the other for a ladder road.

During the excavation of the slices, framed timber is installed at one side of every winze; the height of the timbering is increased correspondingly at every level. Thus, after completion of the mining we will have winzes in the filling (1', 2', 3', fig. 81). These winzes are for the mining of the 28-foot barrier which is to be taken out by working from above downward under the filling.

The use of the system as described requires frequent repairs of the winze which is inside of the filling near the hanging wall. Besides, during the excavation of the last slices of the level, the upper drift, which is inside of the filling near the hanging wall, sinks gradually and requires careful and constant repairing. This danger will probably increase during the excavation of the 28-foot

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barrier pillar; thus the cost of repairs may be very high. The drifts and winzes were driven in the hanging wall because the shafts were located in the hanging wall of the deposit.

In the Dobrovalsky mine in which the ore is from 7 to 14 feet thick the distance between the winzes is 87.5 feet (fig. 82). Twenty-one feet are excavated to both sides of each winze; one winze is left near the 42-foot barrier pillar. The barrier pillars are mined from above downward. Here the level drifts are driven through the ore near the hanging wall (in case of solid quartzites). Barrier pillars 7 feet thick are left, and taken away after the drifts are no longer needed; the mining of these pillars will probably be impossible without some loss of ore. The sections are mined from the shaft, and from below upward; the 42-foot barrier pillars are removed by retreating towards the shaft (from above downward).

In the Ushakov mine the crosscut system along the strike of the ore body is employed. The thickness of the ore is from 7 to 21 feet. The winzes (figs. 83, 84, 85) are opened every 84 feet. Twenty-one feet are excavated on both sides of each winze along the strike of the ore; depending on the thickness of the ore, one or two 10.5-foot stopes are opened. The height of the level is 42 feet. Winzes (g', figs. 82 and 84) are left inside of the filling for the excavation of the 42-foot barrier pillars.

Five slices are mined immediately but the sixth is not mined until the beginning of the mining of the barrier pillars which serve for supporting the upper filling drift. If the ore is soft, a special construction is used instead of the usual winzes. In weak ore a drift parallel to the upper drift is opened in the footwall 14 to 21 feet from the ore (fig. 85).

The crosscut system of mining along the strike of the ore is also used in the region of Krivoy Rog for mining layers thicker than 35 feet. The Losovatsk mine uses this system in thicknesses up to 63 feet (fig. 86). The excavation of the slices is done from above downward, the distance between the winzes being 42 feet. Stopes 21 feet long are opened along the strike of the ore body in the cross drifts from the winzes, as shown in Figure 86. The filling is taken from other stopes or drifts. The level interval is 42 feet. The construction of tramming drifts through the ore was to be abandoned, owing to the great expense of their maintenance. The driving of drifts through the wall rocks is better practice.

This system can be applied under limited conditions only. Where the ore body is thin and the ore as well as the hanging wall rocks is not stable, the system is used only rarely.

The coefficient of economy for the crosscut system, mining along the strike of the ore body, is estimated as follows:

Thickness of layer, 2.00 sagenes; angle of dip, 50°; wall rocks, weak slates.

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Volume of ore in the section to be mined: Thickness, 2 sagenes; height of level, 10 sagenes; along the strike 6.00 sagenes taken out from below upward, + 6.00 sagenes taken out from above downward = 12 sagenes;

$$2 \times 10 \times 12 = 240 \text{ cubic sagenes.}$$

Preparatory work per mining section:

	Sagenes
Drift	12.00
Winze	10.00
First stope of the first layer, about	3.00
Total	25.00

Per 1 sagene of preparatory work:

$$\frac{240}{25} = 9.6 \text{ cubic sagenes.}$$

The coefficient of economy is here greater than in the overhand stoping or bord-and-pillar systems (7.3 and 6.9 cu. sag.). As the system is used mainly for mining ore deposits with weak wall rocks (like the bord-and-pillar system), the preference must be given to the crosscut system, which also allows the work to be performed more safely.

The disadvantages of the system are that mining in the various sections is not carried on simultaneously, the barrier pillars are taken out only after the first 42 feet are excavated, and a comparatively small number of stopes are opened.

4. Crosscut System, by Chambers; Removing the Ore by Successive Slices (the Chamber-Trench System). - The chamber-trench system consists of dividing the ore deposit into short sections and mining alternate sections simultaneously by using cross drifts situated one above the other and working downward. The sections left are mined from above downward. A certain length of time passes between these two operations. As the deposit is divided into short sections with pillars, the name "pillar system" might be suitable.

The sections which are mined first are excavated by means of cross drifts situated one above the other; thus the system has been called the cross-drift system. In the southern region, however, the system is called the chamber-trench system. This expression, being short and sufficiently descriptive, will be used here.

The Ushakov mine applied this method first. In the beginning the drifts were driven through the ore body, but very soon it was found that drifts through the barren rocks of the footwall were more suitable, especially since these rocks were soft clay slates.

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The method of field drifts was also used at this mine, as a more complete extraction of the ore was thus possible. The thickness of the deposit is from 7 to 77 feet, the angle of dip up to 80°. The hanging wall is solid quartzite; the footwall is soft and semisoft clay slates. Deposits over 21 feet thick are mined by the chamber-trench system. The level interval is 21 feet. As the driving of field drifts increases the cost of mining, it would be better to increase the level interval. The chambers are 10.5 feet thick. The 10.5-foot thick pillars are excavated by using cross drifts.

Chambers and barrier pillars are marked off along the drift. If possible, several chambers are opened at the same time during the advance of the drift. The barrier pillars are 10.5 feet wide (figs. 87, 88, 89, 90). The winzes at the beginning of every barrier pillar are opened at the same time. This coordination of opening chambers in the first slices and the winzes from them is preferable because at the end of the excavation of the first slice the latter could be filled from the winzes. There are cases, however, where the winze has not at this time reached the upper level (owing to the thinness of the mining layer, the winze takes more time than that of the chamber). In this case the crosscut is filled either by delivering the filling through the same level or by the method applied in the Karnavatsk mine; that is, the second slice of the chamber-trench may be mined without the filling of the first one by standing on temporary supports. It is not recommended that more than two slices be mined without filling, owing to the height of excavation.

The most unproductive work, during the mining of the first slice of the chamber, is that by cross drifts. Crosscuts leading to the chambers can be turned (fig. 90) so that switches may be installed. The height of the cross drifts varies from 7 to 9.31 feet. Usually it is 8.4 feet. After the ore is mined from the cross drifts, they are filled. The chamber is separated from the drift by lining with boards nailed to the props. A space is left for the future winze. After the cross drift is filled to the height of the next cross drift by means of the winze, the ore is mined by standing on the filling of the cross drift of the first slice. After the cross drift of the second slice is excavated and filled, a winze corresponding to the opening is constructed in the filling of the second slice. The winze is fully lined with 3 to 3½ inch thick boards (dividing it into ladder road and ore compartment), as the time of service of these winzes is very long, owing to the need of later mining the barrier pillars left between the chambers.

Winzes are built in the footwall at the side of the corresponding barrier pillar. After the second layer is filled, the work is continued in the third slice, etc. In this way five trench slices (5 x 8.4 = 42.0 ft.) are excavated; a 7-foot portion is left behind; this is necessary for mining the barrier pillar between the chambers later on.

In case field drifts are employed, complete mining of the level without leaving the roof barrier pillar is possible. Formerly when using this system, preparation drifts through the ore body were employed (fig. 88), and it was necessary to leave roof-barrier pillars. Besides, at that time, in taking out the barrier pillars between the chambers, the working in the upper drift was not safe and maintaining the drift was expensive.

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Considering that the excavation of the first slice of the chamber-trench is accomplished by means of a stope and the excavation of the other slices is done quickly, only weak supports are required. The use of the arch-shaped roof reduces the amount of artificial support required. Besides, it is possible to utilize fully the stulls of the under slices as supports for the other slices. Here, only the support of the winze is expensive.

The barrier pillars between the chambers are mined by means of one single stope under the filling; the winze is used for bringing down the filling and for storing the ore. As the excavation in the slices of the chamber-trenches is completed on the filling of the slices lying below, this filling becomes so compact that the average filling material forms an almost monolithic mass. Therefore after the chambers are mined and the excavation of the barrier pillars is started, the walls (filling of the chambers) stand perfectly.

Depending on the conditions, various sizes of chambers and barrier pillars are used in different mines. Thus in the Nadejda mine, in which the thickness of the ore body is from 28 to 56 feet and the angle of dip is 42°, the chambers are from 14 to 21 feet wide and up to 10.5 feet high; the barrier pillars are 7 feet. The drifts are driven through the ore, so that complete extraction of the ore is not possible.

The Shiroky mine uses chambers 9.21 feet wide and barrier pillars 14 feet thick, as the ore is very soft and the footwall consists of soft slates; the thickness of the ore body averages 42 feet, the angle of dip is as high as 80°, the height of the level is 70 feet, and the field drifts are driven through the slates of the footwalls. If the thickness of the barrier pillars is more than 10.5 or 14 feet the ore is excavated by using one main cross drift from which other cross drifts are opened along the strike from the hanging wall backward.

Other systems of mining the barrier pillars between the chambers have been proposed lately, such as "additional cuts" (Karnavatsky mine) and rasbrytning (Karnavatsky mine, Dubovaya Balka).

At the Chervony mine, in which the thickness of the ore is from 35 to 70 feet, the ore, as well as the wall rocks, is strong; the drifts are driven through the ore body, and the height of the levels is 31.5 feet; this mine has adopted chambers 35 feet wide and barrier pillars from 10.5 to 14 feet thick.

The Karnavatsky and Chervony mines use chambers from 10.5 to 21 feet wide and barrier pillars from 10.5 to 21 feet thick, as the ore and the wall rocks are of medium strength, the thickness of the ore body is from 21 to 105 feet, and the angle of dip is from 55 to 60°.

The Rakhmanov mine has adopted chambers 15.5 feet wide and barrier pillars 15.5 feet thick. The thickness of the ore body is more than 14 feet. The barrier pillars are excavated from above downward. In case of greater thickness, up to 70 feet, regional barrier pillars 15.5 feet thick are left at intervals of 52.5 feet.

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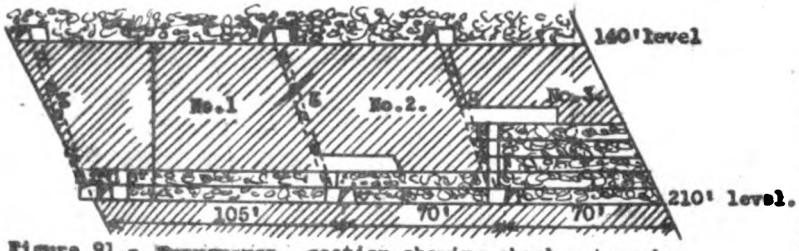

Figure 91.- Transverse section showing chamber-trench system at the Karnavatsk mine.

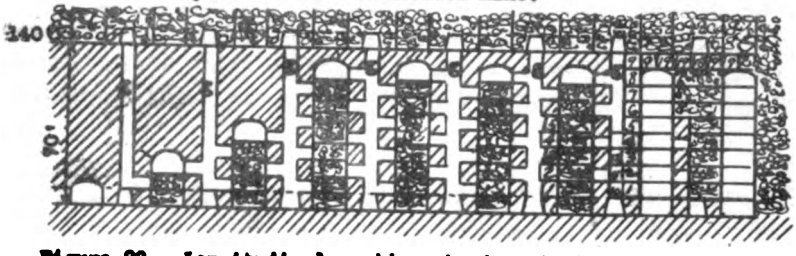

Figure 92.- Longitudinal section showing chamber-trench system at the Karnavatsk mine.

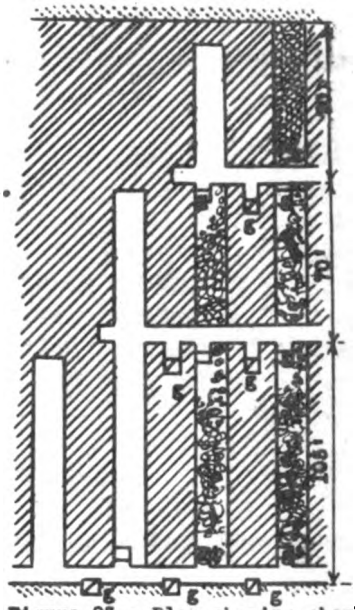

Figure 93.- Plan showing chamber-trench system, Karnavatsk mine.

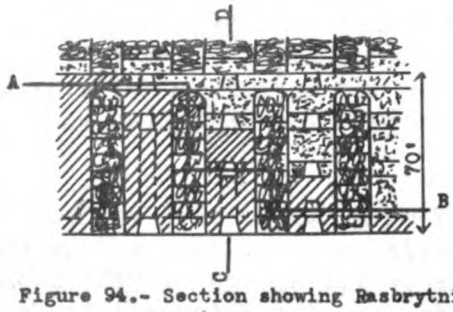

Figure 94.- Section showing Rasbrytning system.

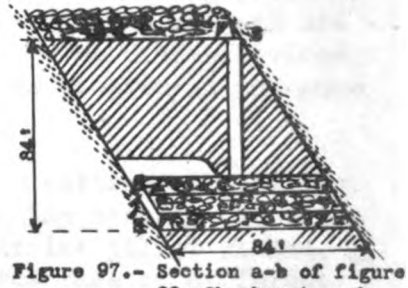

Figure 97.- Section a-b of figure 99, Chamber-trench system.

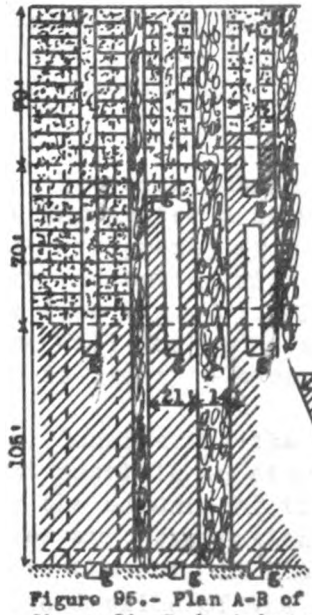

Figure 95.- Plan A-B of figure 94,-Rasbrytning system.

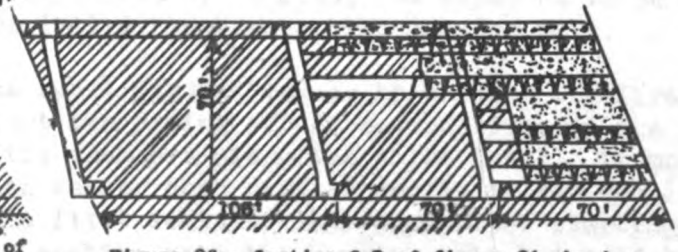

Figure 96.- Section C-D of figure 94 showing Rasbrytning system.

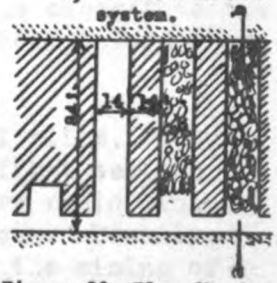

Figure 99.-Plan, Chamber-trench system.

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The Dubovaya Balka mine uses chambers 14 feet wide and barrier pillars 21 feet thick. If the thickness of the ore body is less than 49 feet, the width of the chamber is increased up to 28 feet - of course, only in sections with very stable ore.

The Losovatsk mine, which has an ore body 63 feet thick, solid ore, and stable wall rocks, the drifts are driven through the ore; the width of the chamber used is 21 feet and the thickness of the barrier pillar is 21 feet.

The Veselo-Ternovsky mine adopted 14 feet for the width of chamber-trenches and thickness of pillars.

The Karnavatsk mine uses the chamber-trench system for mining the southern part of the ore body, deposit No. 7, the thickness of which is about 245 feet (figs. 91, 92, 93). Here, the 140-foot level was mined by a system of large chambers, 14 feet wide; barrier pillars left between the chambers were 21 feet thick (fig. 22). The size of the chamber-trenches on the 210-foot level was 14 feet and of the barrier pillars was 21 feet. But in trying to make the mining more economical, tests were made, and as a result these sizes were changed, of course under the condition that the vertical axes of the chambers and pillars must coincide.

Owing to the great thickness of the ore body, therefore:

1. A long time was required for mining each chamber delaying the operation of No. 7 mine.

2. It was necessary to take special measures of precaution, as the roof of the chambers remains uncovered for a long time.

3. Special difficulties were encountered in taking out the big pillars; the mining of the deposit was divided into three parts, two of 70 feet each and one of 105 feet. This was done by connecting the chambers. Two drifts divided the ore deposit into three sections; the mining of these was started at the same time.

The maintenance of the timbered winze increases the costs of the mining; so the Karnavatsk mine used another method of constructing the winzes. Here the winzes were opened from the drifts in the center of the barrier pillar winzes, g, and the connection with each of the neighboring chambers was made at different levels (see fig. 92). The mining of the third part, which was the closest to the hanging wall and had a thickness of 70 feet, was expected to be done before the others in order to have filled chambers at the hanging wall.

Considering the small productiveness in working the first slice, it was thought possible to start the mining of the second slice of the first section during the advance of the chambers along the first level. If more rapid mining is necessary, excavation can be done simultaneously in all sections. Usually, however, the work in the first sections is stopped after starting the mining of the second slice of the section near the hanging wall. A roof barrier pillar 7 feet thick is left in the chambers and a winze, g, is left in the filling of the chamber.

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After the chambers of the third section are mined, the chambers of the middle section and then of that near the footwall are excavated. It was planned to try two different methods in mining the barrier pillars, but the trials were not concluded because of bad conditions in the mining industry in 1918.

a. Mining of barrier pillars by the system of vertical slices (additional cutting)

In mining the pillars left between the chambers it is very important to excavate in the same direction as in mining the chambers - that is, from the hanging wall to the footwall. This must be done in order to protect the upper drift.

Mining by vertical slices (fig. 92) must be started near the hanging wall from the first level upward. The ore which is left is excavated during the mining of the lower level. Only near the drift on the footwall, which is driven in the ore at the Karnavatsk mine, the ore can not be recovered.

The sequence of mining by additional cutting is shown in the figure by numbers; the roof-barrier pillars are taken out at the same time as the stopes 9 and 19. The mining of the first two vertical slices is done from below upward and of the third from above downward under the filling.

b. Mining by the rasbrytning system.

The same sequence in miningby sections is followed in the rasbrytning system (figs. 94, 95, and 96). Cross drifts 7 feet wide are opened from the winzes toward the hanging wall of the section; these cross drifts are spaced at intervals measured from the bottom of the upper drift as follows: 7 feet, 24.5 feet, 45.5 feet, and 63 feet.

From the ends of these drifts, stopes 7 by 7 feet are opened and driven to the center of the roof-barrier pillar (in the first upper slice) or to the filling of the chamber in the slices lying below. After this, the upper slices of the ore are taken on the retreat.

A barrier pillar 14 feet thick is left near the winze for the safety of the latter; it is removed during the mining of the next section. This barrier pillar would be lost if the drifts were driven in the ore body. Therefore, in this system also, the driving of the drifts through the quartzites of the footwall is necessary. (Details of the rasbrytning system are given later.)

In the Dubovaya Balka mine the chamber-trench system was adopted after the ore was taken out in the upper levels by means of large chambers (fig. 21). Here the width of the chamber-trench is 14 feet. Drifts for mining of the chambers are driven near the hanging wall and in the ore body (figs. 97, 98, 99).

The height of the chambers is 84 feet. Raises for bringing down the filling are driven to the upper drift during the mining of the first slice of the chamber; their inclination must be close to 90°. This is most favorable for bringing down of the filling, but, on the other hand, the use of the raise as an

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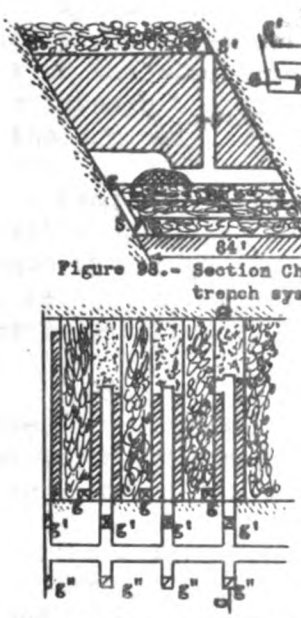

Figure 98.- Section Chamber-trench system.

Figure 101.-Plan showing mining barrier pillars by Raebrytning system.

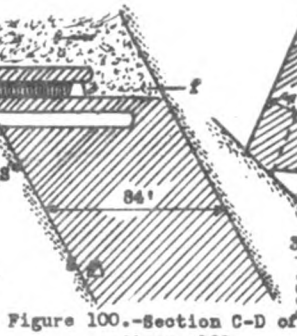

Figure 100.-Section C-D of figure 101.

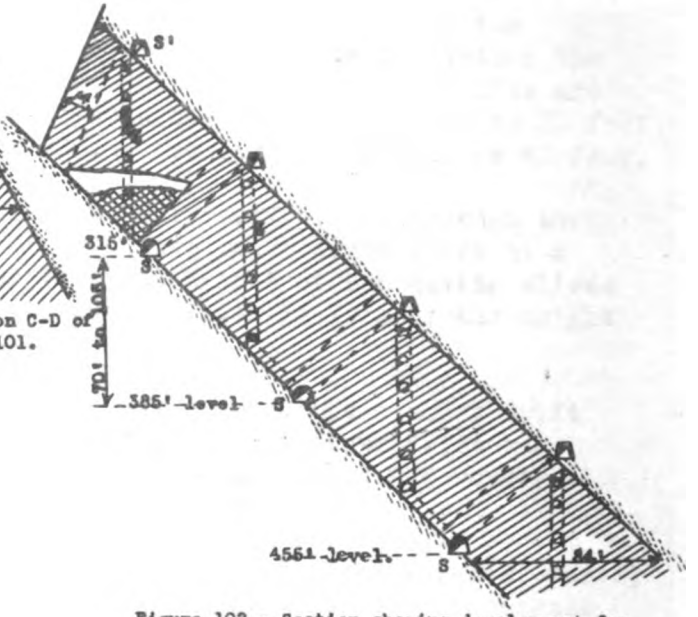

Figure 102.- Section showing development for chamber-magazine system, (shrinkage)

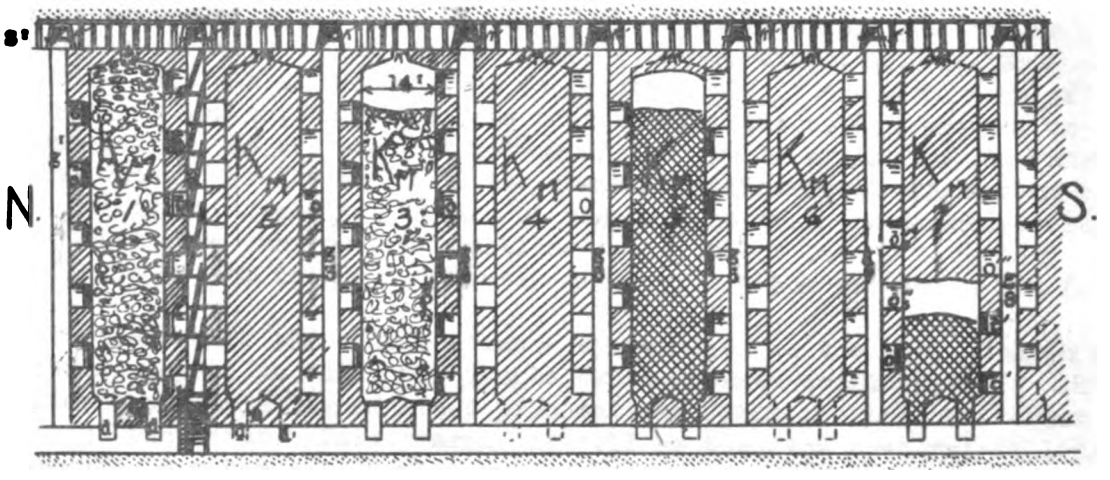

Figure 103.-Longitudinal vertical section showing chamber-magazine system (Shrinkage stoping)

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auxiliary exit in the upper slices becomes difficult (fig. 98). Sometimes mining without filling the two slices and with a partial storing of the ore is adopted (fig. 98).

After the filling of the chambers is completed, the mining of the barrier pillars between the chambers is started by the rasbrytning system; the height of the slices is 14 feet (see figs. 100, 101). In this case drifts are driven through the quartzites of the footwall at a distance of from 14 to 21 feet from the ore body. The level interval for mining the barrier pillars is 42 feet.

From the field drifts, winzes are opened for every pillar through the quartzites; they are connected with the corresponding upper cross drift at a distance of 7 feet from the ore body. The vertical height of the caving slices is 14 feet, the height of the cross drifts and the drifts is 7 feet; the height of the caved slice is 7 feet (see fig. 100).

Caving on one side was used here. From the cross drift a short drift was opened to one side only, and caving was induced; then another drift was opened to the other side, and the ore was excavated (fig. 101). The work was similar in detail to that of the usual rasbrytning system.

The Veselo-Ternovsky mine distributes the winzes, for convenience, partly in the chambers and partly in the barrier pillars. Also, in order to increase the productiveness of the mine the excavation of the chambers is on both sides from drifts driven from the hanging and footwall sides. The breaking of the ore is accomplished from two winzes by means of stopes which meet one another.

The chamber-trench system may be used for any position of the ore, as well as for ore the physical conditions of which are very different (either friable or solid). The use of this system is limited only by the thickness of the ore body; in case the thickness is less than 21 feet the system becomes unprofitable economically, as too small a volume of the ore is excavated per length of the drift and winze. If the width of the chamber is increased, the system becomes that of a crosscut across the strike of the ore; in case the thickness is over 105 to 140 feet some changes and additional development become necessary (see the use of this system in the Karnavatsk mine for a thickness up to 245 feet).

The main feature of the chamber-trench system lies in the short length of the mining sections, owing to which new stopes can be opened continuously, immediately after the completing of stope preparations; thus the productiveness of the mine can be increased. This reason, as well as the fact that wet-filling becomes unnecessary, may serve to explain why this system is used to such a large extent in the region at present. The mining of the chamber-trenches makes possible the mining of the barrier pillars immediately after the filling of the chambers, as this filling becomes solid.

The coefficient of economy by using the crosscut system for an average ore body in this region is figured as follows:

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Thickness, 10 sagenes; angle of dip, 60 to 70°; ore and wall rocks of moderate hardness and tenacity.

The mining section:

(a) Along the strike of the ore body:

Chamber 2.5 sagenes + barrier pillar 1.5 sagenes = 4 sagenes; across the strike, 10 sagenes; height of the level, 10 sagenes. The excavation of the ore in the pillars is done by the crosscut system working perpendicular to the strike.

(b) Along the strike of the ore body:

Chamber 2.5 sagenes + barrier pillar 3 sagenes = 5.5 sagenes; across the strike, 10 sagenes; height of the level, 10 sagenes. The excavation of the ore in the pillars is accomplished by the rasbrytning system of three slices.

Comparison of coefficients of economy of crosscut and rasbrytning systems

Crosscut system (a)		Rasbrytning system (b)	
Volume of the mining section			
4.00 x 10.00 x 10.00 - 400 cubic sagenes		5.50 x 10.00 x 10.00 - 550 cubic sagenes	
Preparatory and cutting work per mining section			
	Sagenes		Sagenes
Of the drift	4.00	.....	5.50
Of the crosscut to the ore body about	3.00	.....	3.00
		Crosscuts to the ore body for the excavation of the pillar 3.00 x 3	9.00
Winze	10.00	Winze through the ore	10.00
		Winze through the barren rocks	10.00
First slice of the chamber	2.50	.....	2.50
		Cross drifts in the caved slices across the strike 10.00 x 3	3.00
Total	19.50		70.00
Per 1 sagene of length: $\frac{400 \text{ cu. sag.}}{19.50}$ = 20.5 cubic sagenes		Per 1 sagene of length: $\frac{550 \text{ cu. sag.}}{70.00}$ = 7.9 cubic sagenes	

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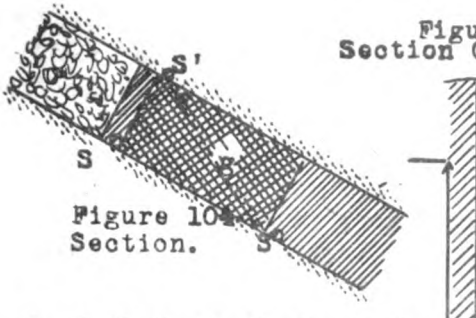
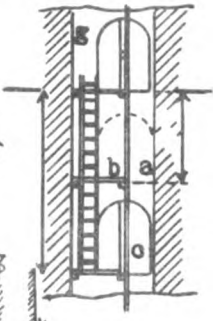


Figure 105.-
Section C-D of figure 106.



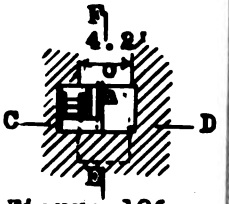


Figure 106.

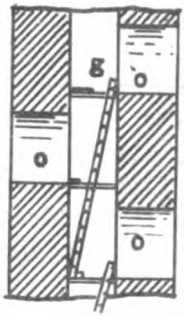


Figure 107.
Section E-F of figure 106

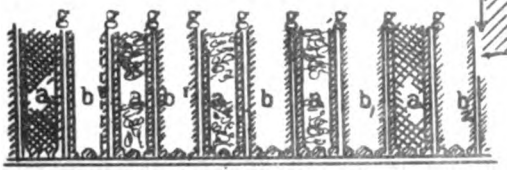


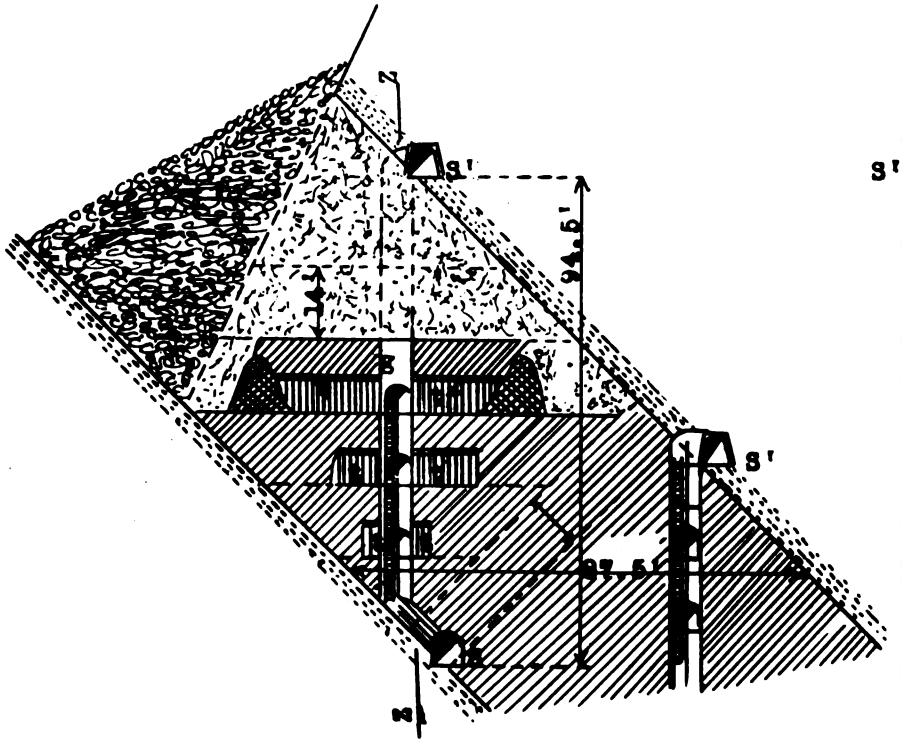
Figure 108.-Longitudinal section.

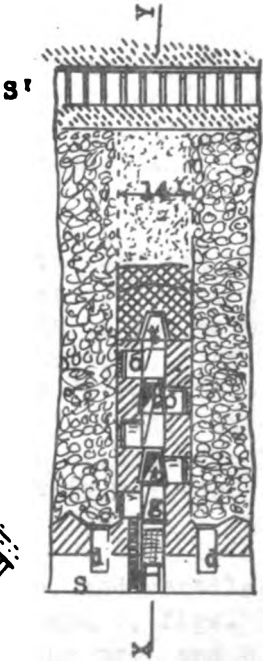
Figures 105, 106, 107 show details of manways.

Figures 104 to 108 inclusive show details of Chamber-magazine system. (Shrinkage stoping.)

Figure 109.-Section X-Y of figure 110.

Figure 110.- Section Z-Z of figure 109.





Figures 109-110 show method of mining barrier pillars.

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Thus, by using the rasbrytning system for mining the barrier pillars, the coefficient of economy is about half.

But, as already mentioned, the "rasbrytning" system becomes more economical and logical for taking out the barrier pillars, owing to the fact that use of the crosscut system from above downward in working the pillars involved many disadvantages, the chief of which are: Slowness of mining; small productiveness of the work along the ore body; necessity of full timbering; and great expense of boards necessary for the covering of the bottom before the filling.

The advantages of it, if compared with the level system, may be summed up as follows: (1) Higher rate of production, as the whole amount of ore can be excavated; (2) the barrier pillars are taken out very quickly; (3) timbering of the whole area is not necessary.

5. System of chamber-magazines (magazine system or magasinsbrytning; shrinkage system). - This system, by which the roof is undermined and the ore is accumulated, is for convenience called simply "the system of chamber-magazines." This is the shrinkage method of mining. The ore deposit is divided by means of level drifts (S, fig. 102), driven through the ore near the footwall, into mining levels each of from 70 to 105 feet in vertical height. The filling drifts are in the hanging wall close to the ore body. The tramming drift and the upper filling drift corresponding to its mining level, are almost in the same vertical plane.

The height of the level depends on the nature of the ore in different places on its thickness, hardness, tenacity, and solidity - as well as on the character of the rocks of the hanging wall; the height of the level is usually from 70 to 105 feet; the vertical height of the chamber-magazines is determined accordingly.

The division lines between two adjacent levels are always inclined; therefore the barrier pillars left between the levels are also inclined (40 - 60°) and have a thickness of from 7 to 10.5 feet. Thus the ore deposit is divided by preparatory development into mining levels bounded by the surfaces of the footwall, hanging wall, and by the surfaces of the barrier pillars.

The shaft field, which is limited along its dip by filling and tramming drifts, is divided along the strike of the ore body into a series of chambers and pillars (fig. 103). The size of the chambers and pillars depends on the physical properties of the ore and at the present time is as follows: chambers, from 14 to 23.5 feet; pillars, from 10.5 to 14 feet. After the level is divided into a series of chambers and barrier pillars, the winzes, g, are opened in the latter, vertically upward if the thickness of the ore body and its angle of dip make this possible, or they are made inclined as shown in Figure 104; in this way the tramming and filling drifts are connected one with another.

The winzes are for handling the ore, movement of workmen, and ventilation of the stopes. The winzes are divided into two compartments (a and b, figs. 105, 106, 107) separated one from another by boards: a for storing the ore, and b for travelling of workmen and for ventilation. The direction of the separating wall

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is along the strike of the ore body, as in this case the compartment assigned for travelling may be used by two neighboring chambers.

The size of the winzes is 5.95 by 3.50 feet. The winzes are lightly timbered. Small cross drifts are cut from these winzes to the neighboring chambers (figs. 102, 103, 107) through which the workmen walk from the winze to the chamber. These cross drifts are distributed in checkered order at every 14 feet and lead to the chambers. They are 4.2 feet wide and 5.25 high, and must be built carefully, cutting the ore accurately to the minimum size necessary.

After the stopes have advanced upward about 14 to 21 feet the preparation of the corresponding chamber-magazines can be started. Two pull holes 3.5 feet wide(d, figs. 103, 110), are cut for the chamber, and in connecting them by stopes, protective pillars are formed over the tramming drift. The mining is started as soon as one of the winzes near the chamber is connected with the filling drift, S', and regular ventilation is established.

The following order of mining a chamber must be strictly observed (1) the chambefs are to be excavated alternately, (2) the excavation must progress from the shaft to the borders of the area mined.

In Figure 103 is shown the excavation in the odd-number chambers 1, 3, 5, 7, etc.; the work in the even-number chambers 2, 4, 6, etc., is to be started only after the waste filling in the neighboring odd-number chambers becomes sufficiently compact to support the hanging wall of the ore deposit.

The mining in the chamber may be divided into two periods: (1) The breaking of the ore and its accumulation in the chamber, and (2) the drawing out of the stored ore.

The first period consists of widening the stopes and advancing the stope upward until the cross drifts leading from the winzes of the neighboring barrier pillars are reached; from this moment on begins the regular mining of the chamber. The pull holes by which the drift is connected with the chamber are closed by trap doors, and only the surplus ore is removed through the holes from time to time.

The further work consists of blasting the roof of the chamber by the workmen standing on the broken ore; the surplus of the ore is removed through the holes so that free space not over 5.6 to 7 feet remains between the surface of the stored ore and the roof of the stope. The weight of 1 cubic sagene of the ore in the solid varies from 80,000 to 90,000 pounds. Let us assume an average of 88,000 pounds.

The weight of 1 cubic sagene of broken ore is about 60,000 pounds. Therefore in storing the ore the volume increases 40 per cent and about 60 per cent of the mined ore may be removed during the work in the chambers. By undermining the roof the connection with the upper gangways is accomplished; those lying below are covered with timber; thus, there are always two gangways by which the chamber is connected with both the winzes; this assures a safe communication for the workmen as well as good ventilation of the stopes.

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The broken ore in chamber 7 (fig. 103) has always closed the first northern (o') and the first southern (o') crosscuts and partly also the second southern gangway (o").

The workmen travel through winze, g, and reach the chamber through O"n; the fresh air current passes through the tramming drift, winze g_5, and reaching chamber 5 through the crosscut, enters the stope; then it moves farther through winze g_6 and goes into the filling drift, S'. In order properly to direct the air current, the mouth of the winze which enters the filling drift, S', is closed by a trap door, k'; this arrangement forces the air current, which rises in the winze, to enter the filling drift and pass through the chamber in which work is going on (see fig. 103, a section along the axis of the winzes between the chambers).

After the filling drift has been reached, the gangway, k, is opened into it; the mining of the chamber is then completed and the second period of work, that of drawing off the stored ore, is begun. Chamber 5 (fig. 103) is shown in this period of work. The ore is loaded through the pull holes of the cross headings directly into the cars in the tramming drift. In the course of drawing, the ore subsides towards the holes owing to its own weight in the shape of a funnel formed on one side by the foot wall of the deposit, the angle of which is about 45°, and on the other side by the surface of the barrier pillar between the levels. The chunks are removed either by small bars or by means of a dynamite cartridge.

After the ore is drawn from the chamber, the chamber is filled with waste rock. The trap doors are removed, the cross headings covered with strong wooden props (oak, if possible), and crushed quartzite and clay is trammed through the filling drift (the proportion of quartzites is about 30 per cent of the whole mass). The filling delivered into the chamber is leveled in horizontal layers about 3 feet thick and is watered. After the settling of the first layer, the second is placed in the same way, and so on until the whole chamber is filled.

During the period of the stoping a given level, the preparatory work for mining the levels lying below is performed, giving due consideration to the matching of barrier pillars and chamber-magazines exactly below the pillars and the chambers of the upper levels.

The barrier pillars between the levels are mined by overhand stoping in the course of transferring stoping operations to the levels lying below. Since the barrier pillars resist the pressures of the hanging wall well, and possibly will not be crushed, their complete excavation is probable.

The barrier pillars left between the chambers are expected to be mined by the rasbrytning method, which is suited to the position of the ore deposits as well as to the character of the ore (figs. 109, 110).

The coefficient of economy by using the chamber-magazine system is as follows:

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Thickness, 10 sagenes; angle of dip, 60 to 70°. The ore is tenacious and of medium hardness; the wall rocks are also of medium hardness.

The mining section:

Along the strike of the ore: chamber is 2.5 sagenes + barrier pillar 2.00 sagenes = 4.5 sagenes

Across the strike: 10.00 sagenes.

The height of the level (inclined in this case) is equal to the distance between the tramming drifts along the line of dip of the ore body for 60°; it is about 12.00 sagenes.

The volume of the mining section:

4.5 x 10.00 x 12.00 = 540 cubic sagenes.

Preparatory and cutting work for the section:

	Sagenes
Tramming drift	4.50
Filling drift	4.50
Winze, about	15.00
Gangway from the winze, about	5.00
	29.00
Cross drifts for the excavation of the barrier pillar by the rasbrytning system	35.00
Total	64.00

Per 1 sagene of preparatory work:

$$\frac{540}{64.00} = 8.5 \text{ cubic sagenes.}$$

The advantages of the system are: A great number of stopes for a small area of ore, safety in working, possibility of working almost without any timbering, possibility of regulating the rate of output of the mine owing to the reserves of the ore in the chambers, and the ability to keep the ore in places protected from the influences of the weather. The disadvantage of the magazine system lies mainly in the necessity of watering the filling, which causes a great delay in taking out the barrier pillars.

The possibility of using the rasbrytning method for mining the barrier pillars left between the chambers, by which the work may be accomplished more quickly, is still not sufficiently proved by experience.

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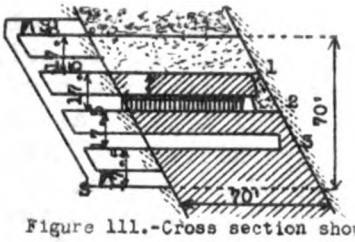

Figure 111.-Cross section showing cover caving system.

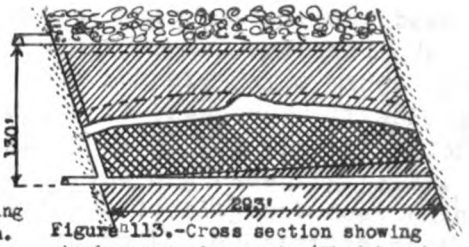

Figure 113.-Cross section showing chamber-magazine system(Shrinkage)

Figure 114.-Plan.

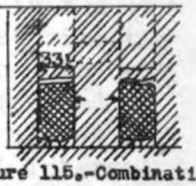

Figure 115.-Combination of shrinkage and caving.

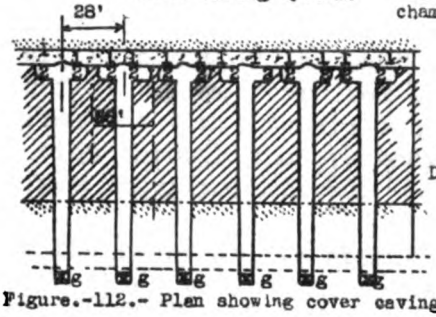

Figure.-112.- Plan showing cover caving system.

Figure 116.- Drift timbering.

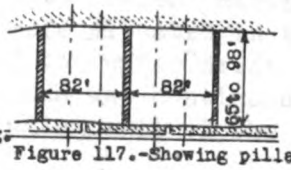

Figure 117.-Showing piller loss.

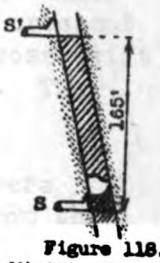

Figure 118.- Mining very thin deposit.

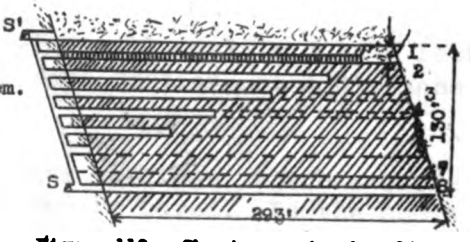

Figure 119.- Showing caving by slices.

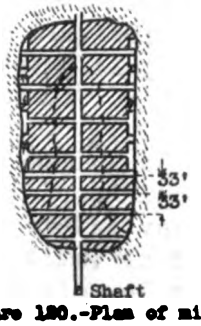

Figure 120.-Plan of mining level, mass caving system.

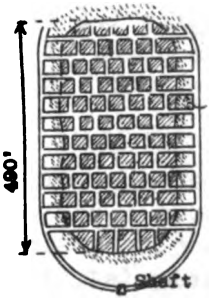

Figure 121.- Plan of level, mass caving system.

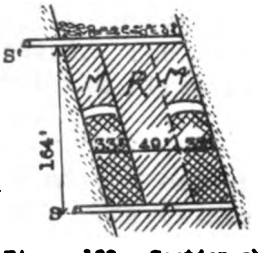

Figure 122.- Section showing combination of shrinkage with pillar caving.

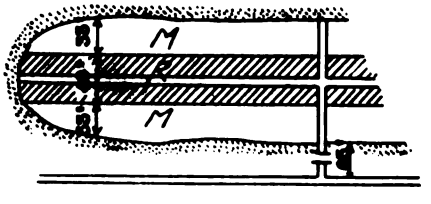

Figure 123.- Plan showing combination of shrinkage with pillar caving.

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6. System of Cover Caving; Removing the Ore by Successive Slices (Slice-Rasbrytning). - The newest system of mining used in the region of Krivoy Rog is that of caving by successive slices or the rasbrytning system. (See p. 46 describing use of this system in Sweden.) This system is employed in the Karnavatsh and Dubovaya Balka mines.

The method used in these two mines has already been mentioned in the description of the chamber and chamber-trench systems. We will now describe the use of the rasbrytning system in the Sukhaia Balka mine. In places the ore body is as much as 70 feet thick; the ore is often very friable and is surrounded by quartzites. The drifts are driven through the quartzites of the footwall at a distance of from 21 to 28 feet from the ore (see fig. 112). The level interval adopted was 35 feet, but owing to high development cost this height was increased to 52.5 or 70 feet. The winzes were in the quartzites of the footwall, spaced at intervals of 28 feet. The deposit was divided into 28-foot mining sections along the strike of the ore body, so that the winzes were situated in the middle thereof. At 17.5 feet to the rear from the bottom of the upper drift a small crosscut was opened from the winze toward the ore body which was continued by a cross drift 7 by 7 feet wide through the ore body to the hanging wall of the deposit. The cross drift was heavily timbered.

From the cross drifts near the hanging wall, drifts 7 by 7 feet were opened to both sides toward the borders of each section, at a distance from the cross drift of $\left(\frac{28-7}{2}\right) = 10.5$ feet each.

By pointing holes in the roof of these workings, which require almost no timbering, a slice of (17.5-7) = 10.5 feet may be caved. In the course of removing the ore, the filling of the upper workings moves also. Therefore, the delivery of the filling material to the stopes is not necessary.

After the ore in the workings 1,1 (fig. 112), is removed, workings 2,2, near the first are started; the ore is caved and removed. The work is continued in the same way, retreating towards the footwall until the first slice, 17.5 feet thick, is taken.

During the mining of this slice another slice of the same thickness is prepared by opening a small crosscut and a cross drift. The excavation must be calculated so that in the vertical plane only one level and only one slice are worked at the same time; in the horizontal plane, however, which is similar to a sublevel, the excavation of several sections simultaneously is possible and usually is accomplished (fig. 112). By the use of a slice 17.5 feet thick the relation of this height to the level interval is determined, as it must be a multiple of 17.5 feet.

Here the increase of the height of the levels is advantageous also, as the amount of preliminary expense is reduced, and especially because the experience obtained in mining ore deposits in Sweden (see p. 46) allows us to expect that in using this system the level interval may be increased to 140 or

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even 175 feet. The heights of the sublevels or slices can probably also be increased up to 38 feet, depending on the properties of the ore.

The question of the widths of the section is quite different where the width must be limited by considerations of safety, and the transportation of the ore. Therefore, for obtaining a fall of 17.5 feet, the width usually adopted is 35 feet.

The coefficient of economy by using the system of cover caving, removing the ore by successive slices is as follows:

Thickness, 10 sagenes; angle of dip, 60 to 70°. The ore is soft and of poor tenacity; the wall rocks are of medium hardness.

Volume of the mining section:

Thickness, 10.00 sagenes; height of level-slice, 3 sagenes; along the strike, 4 sagenes:

$$10 \times 3 \times 4 = 120 \text{ cubic sagenes.}$$

Preparatory work for one slice:

	Sagenes
Lower drift	5.00
Vertical height of the winze	3.00
Crosscut to the ore deposit, about	3.00
Cross drift	10.00
Total	21.00

Per 1 sagene of length:

$$\frac{120}{21.00} = \text{about } 5.7 \text{ cubic sagenes.}$$

Only three slices may be employed for a level height of 10 sagenes. Then, for comparison with other systems, we find:

Volume of the mining section:

$$10.00 \times 10.00 \times 4.00 = 400 \text{ cubic sagenes.}$$

Amount of preparatory work:

	Sagenes
Drift	5.00
Vertical height winze	10.00
Crosscuts to the ore body, 3 x 3 .	9.00
Cross drifts through the ore, 10 x 3	30.00

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Per 1 sagene of preparatory work:

$$\frac{400}{54} = 7.6 \text{ cubic sagenes.}$$

The development economy which is comparatively low for one slice, increases considerably with the increase of the number of slices mined from one level.

Advantages of this system:

1. The whole mining operation can be done without dividing the work into two periods, as is necessary in almost all the other systems.

2. The driving of the winzes through the barren rocks makes the work less expensive, as the maintenance of the timbering becomes unnecessary.

3. The absence of independent filling of the stope makes the work simpler and decreases the expenses of the filling.

4. The mining is more uniform.

Disadvantages of the system:

1. Extra work for maintenance of the cross drifts.

2. Necessity of limiting the work in a level; the work is to be done in one level and one slice only.

3. No control over the composition of the filling material.

4. A certain contamination of the ore by the filling, owing to the almost simultaneous bringing down of the ore and of the filling.

V. CONCLUSION

From the description of all the systems of mining iron ore in the region of Krivoy Rog, one fundamental fact is evident. In order to secure complete extraction of the ore, the thickness of which is more than 14 feet, all preliminary development which is to be used for a considerable period must be done not in the ore body itself but in the wall rocks, preferably in the footwall. A table in which the characteristics of all the methods are shown is added for comparison.

The system best adapted to the mining of ore deposits of small thickness is the crosscut system by excavation along the strike of the ore body. Having the highest coefficient of economy (about 9.6 cu. sag.) and being very productive, the system has only one disadvantage - lack of uniformity, in the mining of temporary barrier pillars.

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Among the systems used for mining ore deposits of great thickness the most logical are the following: The crosscut system, removing the ore by successive slices perpendicular to the strike of the ore body; the chamber-crosscut system, removing the ore by slices; and the cover-caving system.

The chamber and chamber-trench systems require special conditions, such as a considerable tenacity of ore, necessity of semiwet filling, and a certain angle of dip.

The cover-caving system must be considered the most advantageous one; its main disadvantage is the contamination of the ore. This disadvantage can probably be made less serious in the future by use of certain modifications.

In conclusion, a brief description of the main systems used in Sweden is given.

Brief Description of the Underground Mining Methods Used in Sweden

Forms of Iron ore deposits. - Iron-ore deposits occur in the form of lenses of various lengths and thicknesses. The lenses are usually about 700 feet long and of an average thickness of about 70 feet. Sometimes the ore bodies attain a length of 3,500 feet and a thickness of as much as 350 feet; small deposits 280 to 350 feet long and from 21 to 35 feet thick are found also.

The depth of the ore deposits varies greatly; the stratified type extends to depths up to about 3,500 feet. The angle of dip is about 60 to 70°.

Physical properties of the ore. - The average content of phosphorus in phosphorus ore is 1 per cent but is sometimes as much as 5 per cent. The chemical composition is not uniform; the following analysis, however, is typical: Fe, 61 per cent; P, 1.1 per cent; SiO_2, 5 per cent.

The ore is usually very compact and tenacious and is characterized by the lack of fines. About 90 per cent of the ore is in lumps. Stratified structure of ore masses is marked. The hardness of the surrounding wall rocks varies.

Systems of mining. - 1. The oldest system is that of large chambers with pillars; a high percentage of the ore was sometimes lost.

2. The system most used has been, and is at present the crosscut system with stoping by a series of horizontal slices in a direction perpendicular to the strike of the ore body.

3. The roof undercutting system, "tacbrytning" (in the region of Krivoy Rog called the chamber-trench system), is used to some extent also.

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All these systems are used in the region of the Krivoy Rog and do not differ greatly there. The comparatively large number of accidents caused the introduction of new systems: The magasinsbrytning system and the rasbrytning system, as well as the combination of these two systems.

4. The Magasinsbrytning system (shrinkage) is used in cases where the thickness of the ore is from 15 to 300 feet, and the height of the level is up to 165 feet. The ore is broken by overhand stoping. The ore is stored and the surplus is drawn off gradually. In case of greater thickness, the system is used as shown in Figures 113, 114, and 115; here the width of the chamber-magazines is 33 feet and of barrier pillars is 39 feet.

At the footwall there are two strongly timbered winzes, g. The cross drift is timbered with especial strength (fig. 116); about 10 to 13 feet of the ore is not removed, besides. In order to save timber, the drift is driven so that the ore is excavated in slices 10 feet thick. A temporary ore layer, $6\frac{1}{4}$ feet thick, is left in the roof under the upper level and is excavated after the magazine is emptied.

Magazines of large extent have sometimes a width of from 80 to 100 feet; in this case they are provided with two cross drifts; the $9\frac{1}{2}$-foot thick pillars must be considered lost (see fig. 117). The working of deposits of small thickness, 16 to 24 feet, is shown in Figure 118.

One of the difficulties characterizing this system is that of drawing the stored ore. This is accomplished by means of so-called outlets (see fig. 116), which are installed every 10 to 16 feet along the cross drifts. In case of small thickness, very convenient outlets are used, as shown in Figure 118.

5. The rasbrytning system (cover-caving system) is of two types: (a) rasbrytning by slices and (b) mass-rasbrytning.

(a) Rasbrytning by Slices. The ore body is divided into slices of from $16\frac{1}{2}$ to 20 feet high, and the ore is broken in sections up to 50 feet long. Here the levels reach a height of from 130 to 195 feet, and the number of slices in them is from 7 to 10 (see fig. 119).

(b) Mass-rasbrytning. The ore deposit is divided into sections of from $19\frac{1}{2}$ to 65 feet along the level and is taken by cover caving over the whole height of the level - that is, up to 49 feet - 82 feet - 195 feet. The sections were recently reduced to 33 and 49 feet along the level owing to the great area of the ore which remains hanging. In Figure 120 the use of mass-rasbrytning system in mining an ore deposit of 490 by 246 feet is shown. From the crosscut, drifts were first driven every 65 feet. These distances were later reduced to 33 feet and sometimes to 49 feet. Owing to the fact that preparatory development was within the ore body, the whole deposit could not be excavated; therefore in the next level, 541/492 feet, the development was in the barren wall rocks (see fig. 121). Here the excavation drifts were at 33-foot intervals.

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The combination of the magazinbrytning system with that of rasbrytning by slices can be seen clearly in Figure 115. The rasbrytning system is here used for mining the pillars (fig. 115).

The combination of magazinbrytning system with that of mass-rasbrytning is shown in Figures 122 and 123. After the 33-foot magazines situated at the sides of the deposit along its strike are excavated, the remaining 49-foot ore pillar is mined by means of the drift using the mass-rasbrytning system and beginning from the border of the ore body.

The extensive use of the rasbrytning or caving system in Sweden is due to the fact that the ore is subsequently treated by magnetic concentration; for this reason the contamination of the ore by filling material and waste is of little importance.

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Figure 134. - CHARACTERISTICS OF DIFFERENT SYSTEMS USED IN MINING IRON ORE IN THE REGION OF KRIVOY ROG

System	Character of the deposit				Possible dimensions of mining section		Per cent recovery of ore	Filling	Coefficient of economy (volume of the ore in cubic sagenes per 1 sagene of preparatory work) 1/	Main advantages	Main disadvantages	Special conditions	Remarks
	Thickness	Angle of dip	Properties of the Ore	Properties of the Wall rocks	Constant	Temporary (pillars)							
1. Continuous along the strike of the ore (overhand stoping	Not over 14 ft.	40° and more	Of medium hardness and tenacity	Of medium solidity and solid	Height of the level, 42-84 ft. 70-140 ft. along the strike	Under the upper drift along the dip up to 10.5 ft.	Temporary pillars—about 14% loss of the ore	Dry. Settling during the stope operation	7.2 1/	a. Parallelism and continuation of the excavation and filling b. Safety	a. Necessity of careful filling after excavation b. Certain loss of the ore	The wall rocks must be at least of medium solidity. Thickness not over 14 ft.	
2. Bord and pillar, with pillars along the strike of the ore and removal of the ore by rise-workings	Not over 14 ft.	35°- 60°	Moderately hard	Weak	Height of the level, 56-84 ft. Along the strike 105-140 ft.	Under the upper drift along the dip to 10.5 ft., along the strike with interruptions	Temporary pillars, loss about 7%	Dry. Settles by itself	6.0	a. Possibility of use when rocks are not solid	a. Decreased safety. b. Bad ventilation of the stopes c. Great number of blind stopes	Thickness not over 14 ft.	
3. Chamber (large chambers)	Not less than 28 ft. Up to 140 ft.	Over 50°	Of medium hardness and solidity	Of medium solidity and solid	Height of the level, 28-42 ft. Chambers: width 14 ft., height 28 ft.	Roof pillars, 7-11.9 ft. Between the chambers, 14-21 ft.	Complete	Semiwet and wet	3.6	a. High rate of output b. Great number of stopes	a. Necessity of semiwet filling b. Long time necessary for shrinkage of filling c. Lack of uniformity	a. Thickness not over 28 ft. b. Ore of medium hardness c. Semiwet filling used	Temporary pillars may be mined from above downward, removing the ore by sliced and using caved caving. The coefficient is high for the first system
4. Crosscut; removing the ore by slices in a direction perpendicular to the strike of the ore body (transverse level system)	From 21 to 105 ft.	25°-90°	Somewhat hard	Moderate solidity	Height of the level, 21-84-105 ft. Along the strike, 63-70 ft.	Vertical pillars, 7-10.5 -14 ft.	Loss in vertical pillars up to 10%	Dry. Settling during the stoping	15.8 9.8	a. High rate of output b. Safety c. Equality of excavation and filling work	a. Small number of stopes b. Lack of uniformity		
5. Crosscut, removing the ore by slices along the strike of the ore body (level system along the strike)	7-35 ft.	25°-90°	Soft	Of small solidity	Height of the level, 49-84-105 ft. Along the strike, 42-56 ft.	Vertical pillars, 28-42 ft.	Loss in vertical pillars up to 5%	Dry. Settling during the cleaning work	9.6	a. High rate of output	a. Small number of stopes b. Lack of uniformity	Thickness not over 35 ft.	Do.
6. Crosscut, by chambers, removing the ore by successive slices (Chamber-trench)	21-245 ft.	45°-90°	Soft	Of small solidity	Height of the level, 70-84-105 ft. Width of chambers, 10.5-28-42 ft.	Vertical pillars, 10.5-21-28 ft.	Complete	Dry. Settling during the cleaning works	20.5 7.9	a. Great number of stopes b. Equality of excavation and filling work	a. Lack of uniformity		Do.
7. Chamber-magazine system (shrinkage)	35-245 ft.	40°-90°	Of medium hardness and great tenacity	Of medium stability	Height of the level, 70-105 ft. Width of the chambers, 17.5 ft.	Vertical pillars between chambers, 14-21 ft.	Complete	Semiwet	8.5	a. Great number of stopes b. Safety c. Storing of the ore	a. Necessity of semiwet filling b. Long time necessary for shrinkage of filling c. Lack of uniformity	a. Tenacious ore b. Semiwet filling used	The same. The coefficient is determined for mining the pillars by the caving system
8. Cover caving, removing the ore by successive slices	35-105-210 ft.	40°-90°	Soft and weak	Of small stability	Height of the slice of the level, 14-21-24.5 ft. Height of the level, 52.5-70 ft. Along the strike, 28-35 ft.	None	Complete	Uses filling from the neighboring workings	7.6	a. Great number of stopes b. Safety c. Complete excavation d. Uniformity e. Absence of special filling	Contamination of ore by filling material		The dimensions of the section will probably be larger in the future

1/. One sagene = 7 feet.

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